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ABSTRACT

An approach to the computer-aided-design of educational facilities through the simulation of educational activities is described in this dissertation. Such a system can be used by school designers to evaluate and improve school floorplans. The implementation of this system involved: (1) the design and implementation of a systematic procedure for determining those characteristics of a school program which affect or are affected by the physical contraints of a school building, (2) incorporation of those characteristics into a model which could be applied by a simulation system to a proposed floorplan, and (3) the development of computer programs which could successfully simulate educational activities on the proposed floorplan and provide feedback to the architect as to the sufficiency of his design. (Author)

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COMPUTER-AIDED-DESIGN OF EDUCATIONAL FACILITIES

BY

WILLIAM S. BREGAR

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Computer-Aided-Design of Educational Facilities

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Under the Supervision of Professor Richard L. Venezky

This dissertation describes an approach to the computer-aided-design of educational facilities through the simulation of educational activities. Such a system can be used by school designers to evaluate and improve proposed school floorplans. The implementation of this system involved 1) the design and implementation of a systematic procedure for determining those characteristics of a school program which affect or are affected by the physical constraints of a school building, 2) incorporation of those characteristics into a model which could be applied by a simulation system to a proposed floorplan, and 3) the development of computer programs which could successfully simulate educational activities on the proposed floorplan and provide feedback to the architect as to the sufficiency of his design.

A classroom observation scheme was devised which focussed on the physical aspects of elementary school activities. Of particular interest was the grouping of students and their configuration within an observed space for selected instructional activities. Also included in the observation scheme were characteristics of activities which would affect the placement of activities in open-school floorplans and information pertaining to the use of furniture and equipment in the observed activities.

Traditional and multiunit schools were observed and the collected data were analyzed to ascertain significant factors pertaining to the use of space. Results showed that group size varied significantly as a function of school program and activity. Models of activity duration were derived which, in combination with group size, would allow schedules of activities to be generated. Activity descriptions were created to provide a model for generating furniture and equipment requirements, the configuration of students in the space, and the optimal space requirements necessary to carry on the activity given these two characteristics.

A prototype system of computer programs was designed and implemented which would accept 1) parameters consisting of a school program designation, a student enrollment figure, a simulation time step, and a space calculation mode, and 2) inputs consisting of a proposed floorplan and a schedule of blocks of time to be allocated to activities. Using the designated school program model the system generates schedules of activities and their characteristics, then attempts to fit them to the proposed floorplan. Outputs

from the system provide information concerning the potential use of space on the floorplan in terms of the amount and type of space in use throughout the scheduled day.

Emphasis in the programmed implementation of the system was placed on the problems of representation of floorplans and in the assignment of scheduled activities to spaces.

A tree structured representation of floorplans was developed which reflected the hierarchical subdivision of space observed at the sample schools and which allowed relatively easy and direct access to the resources and properties of the space.

Because of the space-subspace relationship allowed on floorplan designs which could be input to the program, linear programming assignment algorithms were not applicable and other standard approaches to assignments of activities to spaces were not feasible. Therefore, a heuristic approach to assignments was taken which produced reasonable, if not optimal, results, thus allowing the final evaluation of space use to be derived from a representative assignment of activities to spaces.

Richard L. Venezky

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

This paper will describe a computer-aided-design system for use in evaluating and improving proposed school floorplans. The implementation of this system involved 1) the design and implementation of a systematic procedure for determining those characteristics of a school program which affect or are affected by the physical constraints of a school building, 2) incorporation of those characteristics into a model which could be applied by a simulation program to a proposed floorplan, and 3) the development of computer programs which could successfully simulate educational activities on a proposed floorplan.

What is presented here is an approach to the solution of a class of what might be called "floorplan design problems". Many different interpretations can be given to the concept of floorplan design. For example, if one is given a list of rectangular rooms and dimensions and a rectangular space into which the rooms are to be placed, then the set of solutions to the problem includes exactly those configurations of the space where all the rooms are properly contained in the space and no room overlaps with any other room.

Furthermore, additional criteria may be introduced and thus increase the complexity of the problem. For example, the dimensions of the rooms and the space might be specified as a range of allowable dimensions instead of a specific set. Constraints might also be added which would designate the orientation of spaces to one another and the allowable distances between spaces.

Within the rooms themselves, a floorplan problem can be defined in terms of the placement of objects into the space. The size and shape of such objects and their relationship to one another may affect their eventual positioning and orientation in the space. Finally, the uses to which the rooms are to be put can and should have an effect on their size and shape as well as their orientations to one another and their relative locations on the floorplan.

1.1.1 Some Notes on Design Theory

According to Alexander [1], the ultimate object of design is form. Form is something over which a designer has control. It represents the solution to a design problem defined by a sometimes vague context. The reason "context" is a nebulous concept is that the degree of fit between a form and its context can often only be expressed in terms of how well the form neutralizes potential "misfits". That is, a bad fit would yield discernible points of failure which could be fully described and theoretically neutralized in a different realization of the form. Although it might be possible to correct one point of failure and yield a "failure free" design, there is no guarantee that correcting several failure points won't result in an entirely new set of bad fits.

It remains to be defined what exactly are the points of failure in a design, and by what process such points are to be detected. In architecture there exists a different set of points for each class of building; houses, office buildings, apartment houses, airport terminals and schools clearly are designed under quite different contexts. Failure in an apartment building might be an inadequate number of three-bedroom apartments whereas failure in an airport terminal building might be an excessive walking distance between connecting flights; aesthetic properties alone could determine the failure of a particular house design.

The complexity of design problems demand a great deal from the designer. As Alexander puts it, "the individual designer's inventive capacity is too limited for him to solve design problems successfully by himself". Negroponte [24] takes the view that a symbiotic man-machine relationship can be developed through which the design process takes the form of an interactive, dynamic dialogue. Furthermore, the machine, intelligent in its own right, and the man learn about each other and so learn to work well with each other. In addition to a high level interactive ability, the machine must also put forth design information which is context dependent; such a realization does not currently exist and is relatively far off. While it may not be possible currently to automate the entire design process for all domains, it may be automated for some domains and partially automated for others in such a way as to augment and complement the designer's ability to create a solution to his specific problem.

What parts or how much of the design process is automated depends on the purpose, philosophy and economical constraints of the object to be designed. If the purpose is to emulate human abilities in design, then perhaps the design process in its entirety should be automated. This would be a distinguishing feature of computer-implemented-design as opposed to computer-aided-design. It could also be properly identified as a form of artificial intelligence. In a computer-aided-design context, it might be more desirable philosophically to allow the human designer more latitude as a professional but provide him with substantive feedback and speedy responses so that he may improve his design. The question now focuses on what feedback should be provided and how much "substantive" is. Clearly a computer can amass and output enough data to inundate any designer; thus judicious use must be made of this facility for it to be an efficient, functional aspect of the design process.

1.1.2 The Design Process in Educational Architecture

The design process as it applies to this thesis is limited to the architectural domain. Within this domain a portion of the context for the design of elementary school floorplans is defined and used as the basis for a simulation procedure. Results from the simulation are summarized and presented to the designer of a floorplan in a form which can aid him in determining the sufficiency of his design.

More specifically, an elementary school is an example of a facility which has to accommodate a large variety of events which are scheduled over a period of time. Other facilities having this property include recreational buildings, convention halls, and playground layouts. The events taking place in these facilities are activities. To provide feedback to a school designer, these activities are characterized and simulated against a proposed floorplan. Spaces in the floorplan are then evaluated in terms of the degree to which their resources, including area, satisfy the requirements of the activities which are to take place. The evaluation consists of a tabulation of space use over time--which spaces are being used, how often and how efficiently they are being used. Central to the evaluation are the results of the decision making process involved in determining at a given time how a set of scheduled activities is to be assigned to a set of available spaces. In the research to be described, a human-information-processing approach is taken toward the solution of this problem. The problem solving representation of the system interacts with a logical, efficient hierarchical floorplan representation to produce reasonable although not necessarily optimal solutions to this "activity assignment" problem.

1.3 Design Problems in Education

"The design of the school must be consistent with the type of instruction systems carried on" [10, p. 51]. The evolution of teaching methodology in the United States has historically been accompanied by changing school structures to accommodate them. The one room schoolhouse of the nineteenth century has been transformed to the egg-crate construction of the first half of the twentieth century and finally to the open-plan schoolhouses of the past decade. The egg-crate design came about as a response to the requirement of absolute independence between grade levels; the open-plan in response to the attempt to abolish grade level differences and open lines of communication among teachers and students [20].

It is instructive to trace some of the changes in elementary school methodologies and their influence on school design.

1.3.1 Traditional Schools and Early Variations

To exemplify the effects of differing educational programs on spatial requirements, first consider what is generally thought to be a traditional school system approach.

Although there has never been a single monolithic system which could be defined as the traditional educational methodology, there are certain characteristics which could be generally attributed to the concept. Among these characteristics are 1) a one teacher per class organization, 2) an age graded division of students and 3) an emphasis on teacher-centered group instruction. The graded school concept, embracing much of the "traditional" approach to education has persisted from the 1860's to the present. As was mentioned previously, the self contained classroom was the architectural interpretation of the independence of grade levels.

The first variations of the traditional methodology appeared in the late 1800's and early 1900's. The majority of these programs were designed to individualize instruction so that students could proceed through grades at their own pace. Among the alternatives were the Elizabeth Plan, the Pueblo Plan and the Cambridge Plan, each of which employed some form of ability grouping [33]. They were all administrated in graded schools, however. Higher ability groups, for example, did more work but remained in the same grade. As such, these methods placed no additional demands on the school facility which could not be met by the self contained classroom.

Further attempts to individualize education were made in the 1920's and early 1930's. The 24th Yearbook of the

NSSE defines two main types of plans designed to provide for individual differences: Type 1--those which attempt adjustments without breaking up the basic class organization, and Type 2--those which emphasized strictly individual progress and much individualized (one-to-one) instruction in essential subject matter [35].

Some instances of the Type 1 plans include Detroit's XYZ multiple track plan, the Batavia Plan which involved "coaching and encouraging laggards", the Gary Plan which employed platooning and Reavis and Miller's independent attempts to individualize instruction through differential assignments, thus holding students to the same rate of progress [35]. Each of these plans recognized individual differences among students but maintained the heterogeneous groupings common to traditionally oriented schools, thus creating no requirement for architectural change.

Perhaps the best example of the Type 2 plan was the Dalton Plan introduced by Helen Parkhurst around 1922. Basically, the plan used a sociological approach to individualize instruction by having students draw up contracts which would define the scope of their work for a month. This would permit them to budget their alloted time according to their own needs. The Winnetka Plan, also of early 1920 vintage, divided the curriculum into common essentials (consisting of basic subjects) and group and creative activities such as music, art, and physical education. Students worked individually on common essentials using carefully prepared materials, and moved through planned sequences of these materials at their own rate [33].

The Type 2 plans were aware of the restrictions of the lock step environment, and could have had an impact on school architecture. In fact the Winnetka Plan resulted in the Crow Island Elementary School which has been cited by the American Institute of Architects as a precursor to modern school architecture [3]. There was no general acceptance of these plans, however, and, for the most part, the egg-crate school design has endured.

1.3.2 Alternatives to Traditional Schools

In the 1940's and middle 1950's two major innovations in instructional methodology appeared which would come to have a great impact on both the organization (staff and classroom) and the physical design of American schools. These were the development of non-graded schools and the implementation of team teaching.

According to Goodlad and Anderson [11] , the non-graded school is an organization designed to implement continuous student progress, thus recognizing the substantial individual differences between students. Goodlad and Anderson further point out that "non-graded" schools appear not to have adopted a uniform set of characteristics". They are themselves individualized with respect to the "innovations developed after entry into non-grading" [11 , pp. 208, 209]. Interest in non-graded schools increased slowly through the 1950's but more quickly in the 1960's where by 1969 about one elementary school in four in the United States was attempting to convert to a non-graded program [33].

Team teaching first emerged in American education in 1954 and has experienced a rapid growth rate ever since [32] . Like the non-graded concept, it is not restricted to elementary schools but its primary impact has occurred in that domain. Shaplin defines team teaching as an instructional organization involving teaching personnel and the students assigned to them, in which two or more teachers are given responsibility, working together, for all or a significant part of the instruction of the same group of students [31].

Team teaching and the concept of non-grading in themselves and some more recent methodological innovations (which drew upon the former concepts in their development) have evolved through definition and practice to a much greater extent than their predecessors--with consequent acceptability. Furthermore, an informal analysis of a sampling of these concepts will show that they can and do have architectural consequences.

The Nongraded English Primary School

As an example of a non-graded school organization, the non-graded English Primary School, which has been the subject of much research can be said to be organized in a "project oriented" fashion. Elliot Eisner, who made a comprehensive study of the English Primary School [9] describes how pupils are given their choice of several projects which they can pursue during the course of a school day. If they finish or tire of one project, they are free to move on to another. In contrast to traditional schools there is relatively little teacher-centered instruction and more of a tendency for students to work in small groups.

The grouping of students in this continuous progress school can and should be a factor in the consideration of school floorplans to house these methodologies. In many non-graded English Primary Schools "the boundary of the classroom and the rest of the school is not so clearly delineated as is the classroom in the traditional school."

(Eisner, op cit.) In the non-graded school the variation in grouping can result in enough small groups competing for space in a self-contained room that the walls begin to inhibit the activities which could take place. A report of the Educational Facilities Laboratories states that while attempting to implement innovative educational procedures "many a school administrator has felt thwarted 'because the building wouldn't get out of the way.'" [13, p. 15]

Team Teaching

Team teaching is an example of a staff oriented organization which can have an effect on school design. Although no one set of characteristics can accurately portray a given team teaching school, two properties--shared decision making on the part of the instructional team and new groupings of pupils--have been cited as pertinent factors in the consideration of school designs for team teaching. Cyril Sargent of the Educational Facilities Laboratory [30] applies these properties in defining a set of four design requirements for team teaching schools to function effectively:

1) they must accommodate groups of various sizes ranging from 2 or 3 to 100 or 200.

2) they must accommodate fluidity in the movement and reorganization of groups which may be changing continuously and at non-standard times

3) there must be a place for teachers to work--both in private and in groups as teams

4) the school may have to be adapted to more students working independently by providing private spaces for study and research

Sargent goes on to cite three architectural "solutions" to the design criteria proposed. These are the open-plan school, the loft plan and planned variability. The open-plan provides one or several areas with no interior walls, the loft plan is a modular one with moveable interior partitions and planned variability attempts to build into a structure the basic spaces necessary to accommodate the groups of students and teachers according to their most likely needs. For planned variability Sargent states that enough must be known about the "recording of student groups and teacher teams to permit the planning of spaces to fit the needs of groups of varying size and purpose."[30,p.229] A major component of this thesis is the design and testing of a procedure to collect and analyze information about the dynamics of grouping under different methodologies for the purpose of determining space needs.

Individually Guided Education

A more recent alternative to traditional instruction is Individually Guided Education, a total integrated system of education developed at the University of Wisconsin Research and Development Center. The instructional components of IGE are encompassed in the multiunit school concept, which is based on 1) a team of teachers administering one of several separate independent units* in a school, 2) a non-graded division of students, and 3) individual, one-to-one (student/teacher), small group, and large group instruction with the emphasis on the student as an individual [17].

The spatial configuration of a school under the IGE organization can be considerably different from that of a traditional one. A team of teachers administering a unit needs to interact continually to coordinate activities. Closed classrooms, while not an impossible barrier, can inhibit the communication among members of the team. The non-graded division of students changes the number of separate class entities, hence their size. This number is usually reduced yielding three or four units, each containing children whose ages might vary by two or three years. The reduction of the number of class units increases the number of students in each, resulting in a need for larger unit meeting spaces. At the same time the emphasis on individual and small group modes of study imply a need for smaller spaces to carry on activities. Such spaces are usually created as subspaces within the larger unit space. This analysis is summarized as one of the stated desired conditions for the successful implementation of an IGE organization.

---

*In practice, a K-6 primary school usually has three units corresponding roughly to grades 1-2, 2-4, and 4-6.

> "The school building is constructed or remodeled to facilitate IGE practices. Pods of varying shapes and sizes in recently constructed buildings accommodate 75 to 150 children and permit one-to-one, small group, class size, and total unit activities. Older buildings are remodeled so that there is one large central IMC that accommodates up to 90 intermediate-age children and another that accommodates at least 60 primary age children in a school of about 600 enrollment." [17, p. 7]

It is clear that the expectation of the designers of IGE is that a pod will be subdivided as necessary for simultaneous use by students in groups of varying sizes.

In general, spaces in an elementary school will be used for a variety of activities. In a traditional closed classroom, virtually any kind of educational activity may be expected to occur. Art, music, reading, math, and science may all be accomplished at the same desk. In the multiunit school, where there is likely to be more group movement, some spaces are often designed as dedicated spaces where particular activities will almost always be scheduled. Other spaces will be designated as general instruction areas and will have to accommodate the usual variety of individual and group instructional activities. How individual spaces are put to use, how often and to what extent they are used is determined by the method for assigning scheduled activities into the available spaces.

Compounding the design problem for school buildings is the factor of a constantly changing enrollment. Schools are usually constructed in a district or area which reaches some minimum population level. For a growing community it does not make good sense to build a school which will accommodate its current population. Neither does it pay to overcompensate for an expected enrollment figure. It is difficult to assess the impact of changing enrollment on the functionality of an elementary school. A well designed school with carefully planned and scheduled activities can survive a substantial increase in enrollment without significant overcrowding.

To recapitulate, the design of educational facilities is a problem which must be concerned with satisfying methodological differences between schools, allocating space among scheduled activities, and remaining sensitive to changing enrollments.

1.4 Approaches to Educational Facilities Design

Every state has codes which specify legal standards which all school buildings must meet for construction materials, ceiling heights, fire and safety regulations, sanitary facilities and so on. The school architect, however, is concerned with not just the physical aspects but also the functional factors--a more subjective set of criteria. According to Paul [27], these should include requirements which might be classified as global (school and community wide) and local (classroom or spatial) requirements. To be considered globally are school philosophy and school methodology as has been previously discussed (Section 1.3). Local considerations besides classroom objectives include space needs for activities and functional relationships between spaces. Among others, the Pilkington Research Unit [29] would add to these requirements one of adaptability to meet changes in educational aims and practice.

Adequate traditional school buildings can be constructed, according to Castaldi [7], by following guidelines such as those shown in Table 1-1. Future schools would have additional facilities for individual study in carrels, and space for programmed instruction and specialty rooms for construction or workshop activities and remedial

TABLE 1-1

TYPES, NUMBER, AND SIZES OF SPACES IN A CONVENTIONAL ELEMENTARY SCHOOL (A Partial Listing)*

Type of Space	Number Needed	Normal Class Size	Total Sq. Feet
Kindergarten	1 Per 20 Students	20	1100-1300
General Classrooms	1 Per 25 Students	25	900-1000
Remedial Rooms	1 Per 5 Teachers	6-10	
Auditorium			8 Sq. Ft. Per Persons

---

*Excerpted from Castaldi [7].

TABLE 1-2

FORMULA FOR COMPUTING NUMBER OF INSTRUCTIONAL AREAS IN A NON-GRADED SCHOOL*

$$\text{Number of Areas} = 1.25\,\frac{E}{C}\cdot\frac{n}{N}$$

where E = Total Number of students requiring space for a given group size

C = Number of students in a given group or class

n = Number of minutes that a given group size meets per week

N = Number of minutes in the school week.

Example: Assume an elementary school program calls for 300 students to meet in groups of 16 for 10% of the time. Let $N = 300$.

$$\text{Then Number of Areas} = 1.25\cdot\frac{300}{6}\cdot\frac{30}{300}$$

$$= 6.25 \simeq 6 \text{ spaces.}$$

---

[*] Excerpted from Castaldi [7].

instruction. For non-graded schools he attempts to define the number of spaces necessary to accommodate a particular group size as a function of total number of students to be broken into groups, time (in minutes) per week which that group will meet and number of minutes in the school week (see Table 1-2). Even though this model might predict the number of spaces necessary, it is based on the assumption of a fixed schedule of activities. The question of how much area to allocate to each space is not directly addressed.

To design buildings for educational methodologies which attempt to individualize education through non-graded multi-age grouping, school designers have turned increasingly toward an open-plan school design. Engelhardt [10] considers the activities which would likely go on in a continuous progress open-plan school, the factors to be considered in planning such a school, the relationship between spaces (Figure 1-1), and then prescribes space requirements to accommodate the program. The requirements for square feet per space are presented as sample values, however, the method for determining the area requirements are nowhere described. The effect of the schedule of activities on space requirements is not considered.

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OPEN-PLAN SPACE RELATIONSHIPS

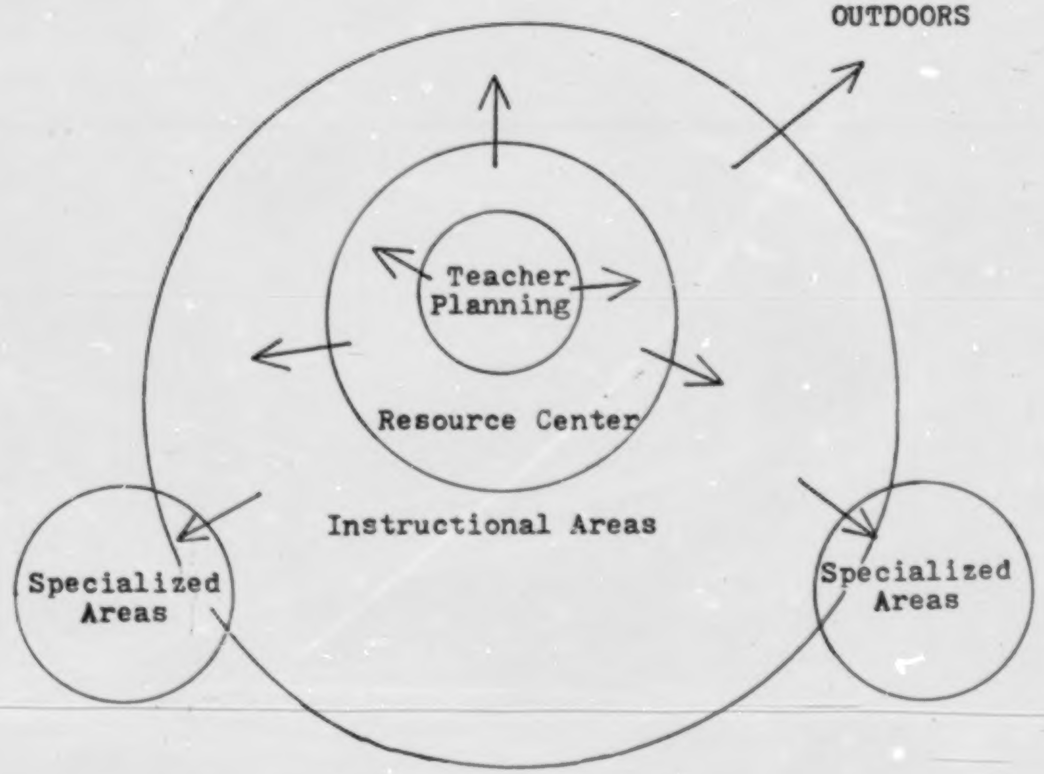
OUTDOORS
Teacher Planning
Resource Center
Instructional Areas
Specialized Areas
Specialized Areas

Figure 1-1

Castaldi and Engelhardt are representative of those who can establish good general guidelines to follow in designing a school building. The effect of such generality is manifest, though, in the wide range of interpretations embodied in existing elementary schools. A comparison of award winning elementary schools in Nation's Schools [16] showed a difference in space allocation of from 54.2 to 112.3 square feet per student with costs ranging from $10.80 to $33.84 per square foot. Instructional space ranged from 40% to 80% of the total area of the facility.

A better attempt to define space needs in terms of area requirements has been made by Banghart and others at Florida State University [4]. The model is appropriately applied to high schools and uses a building block approach where the basic unit is a student module. A student module is defined as "the space and resources required to maintain a student in a given activity at a particular time". Activities are categorized into nine types which include such classes as general class activities, art activities, and laboratory activities. Each has a student module associated with it. Space needs are determined by simulating schedules of activities based on previously compiled information on student requests for activities, duration of the activities and the number of activities requested per student.

The promise of the FSU approach is that it can accurately deliniate space needs based on known information about educational activities in high schools. However, the method by which the student module dimensions are determined is not outlined. Though these might be more standardized at the high school level, this is not necessarily the case at the grade school level. Further, all instructional activities are grouped into one class under the assumption that for such activities, the student module is an interchangeable unit. Again, in elementary schools with different methodologies, this may not be applicable as is shown in Chapter 3.

The approaches described provide guidelines, general and specific, for determining the amount of space an educational facility might require, assuming the per-student space needs figures they utilize in their models are correct. It is conceivable that the FSU simulation could be applied to a proposed floorplan to test its adequacy. Apker [2], using available seating as his spatial denominator, did just that. He simulated a high school with modular scheduling in order to make better decisions about space needs. The high school had not yet been built at the time of the simulation. Among the questions answered by Apker's system was "Could better decisions be made regarding building needs when using simulation?" The results showed that for a school of 1500 students the architect overestimated classroom needs by 21 rooms and underestimated seating space for large group instruction. The scheduling for Apker's simulation performed by the Generalized Academic Scheduling Program (GASP). Using a computer to generate complex schedules for modular schools has in most cases proved to be superior to manual methods both in quality and cost [23].

FSU and Apker do provide some basis for testing floorplans. As they are applied to high schools they can provide valuable information for school designers. The high schools involved, however, do not appear to present the problem of the effect on space of varying methodologies. That is, by assuming the "traditional" mode of education, space needs can be translated into seating requirements within a fixed space. Apker and FSU also have the advantage of being able to work with fixed, regular schedules which can be based on past student requests. Applying the appropriate scheduler to the student requests and a space list yields a complete schedule of activities, where they will be located, and with appropriate inputs, the instructors who will supervise the activities. This information is sufficient to determine the use of space over time in the educational facility to which the simulation is applied.

1.5 The Design Problem for Floorplans

The foregoing discussion lays a basis for specifying the design problem of developing viable school floorplans. The characteristics of the problem can be described in terms of requirements, constraints, and criteria. Requirements are a function of a particular educational methodology; they are derived from an analysis of the activities which take place in an elementary school. Activities have certain characteristics--they are scheduled at certain times, they require resources such as space and equipment, and they involve groups of people. Constraints may also be placed on activities such as through the assignment of priorities or by virtue of their relationship with other activities. The floorplan, to be satisfactory, must meet certain criteria. It must provide enough space to contain the activities scheduled at particular times; the resources of the spaces must adequately meet the needs of the activities; and it must allow activities to satisfy the demands of their constraints.

Certainly, there is a good deal of subjectivity associated with the evaluation of a floorplan as has been described. What is an adequate amount of space for an activity according to one set of school administrators might be inadequate to another. Factors ranging from the aesthetic to cost considerations might affect such judgments. The adequacy of a school floorplan for a given educational program can be defined for the purposes of this report as a function of the amount and configuration of space available for carrying on educational activities under that program.

It is because of the subjectivity involved in determining what is a satisfactory design and what isn't, as well as a conscious decision not to automate the design process--thus leaving the more creative aspects of design in the hands of the architect--that this research is directed toward the development of a tool to augment the design process.

1.6 Method of Implementation

It is the purpose of this thesis to show that appropriate, useable information about the floorplan of an elementary school can be presented to a designer through the vehicle of a computer simulation. The kind of simulation employed is known as a discrete simulation--one in which all changes in the system modelled are assumed to occur at discrete points in time [17]. That is, the simulation is a function of a set of events which happen at different times but whose effects can be assessed and incorporated into a model at some discrete moment in simulated time. The events in this case are activities and their major effects is their impact on the available space in a school at the times they occur. It is important, furthermore, in view of the number of differing educational methodologies in current use, that the simulation be sensitive to the differences, if any, of the effects upon space use of one methodology versus another.

To provide a basis for demonstrating such a sensitivity, a systematic method for modelling elementary school activities was developed. Through the direct observation of elementary schools operating under different scholastic progress and the subsequent analysis of the data recorded, characteristics of activities were classified and incorporated into a data base of "activity descriptors" from

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which simulated activities could be generated. The data items which were recorded included a floorplan drawn to scale detailing instructional spaces, information on how students were grouped for activities, and the time and duration of each observed activity.

Utilizing the information in the data base is a system of computer programs which, according to a set of input parameters, generates likely sequences of activities and their characteristics, steps at user designated time intervals through the schedule, and at each time step attempts to find spaces on the proposed floorplan into which to assign the activities. Upon the completion of the assignment phase, the system collects information on the status of space in the school and builds a report which provides that information to the designer.

Chapters 2 and 3 of this dissertation document the development of the observation procedure and the method and results of analyzing the data collected in the process. Chapter 3 also details the construction of the activity descriptors for one of the two multiunit schools which were observed in a field test of the observation procedure. Chapter 4 gives a functional description of the simulation system including parameters to and the flow of data through the system. Chapters V and VI describe the approaches taken

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to the problems of floorplan representation and the assignment of activities to spaces at each time step during the simulation. Chapter 7 analyzes the results of running three selected test cases through the simulation process; Chapter 8 summarizes the work and offers suggestions on implications for future research.

CHAPTER 2

Development of a Model of Educational Activities-
The Observation Procedure

2.1 Introduction

This chapter will describe the development and implementation of an observation procedure for collecting data which would characterize the actual and potential impact of elementary school activities upon instructional space. The objective in collecting data was to show that the implementation of different scholastic programs can result in schedules and physical configurations of activities which would lead to different architectural conceptions. The utility of the procedure is its ultimate application to the development of mathematical models of elementary school activities.

The success of a simulation of a system is strongly dependent on the validity of the model employed to represent the system. For many applications enough is known about the variables involved to derive a theoretical model for a system. For physical phenomena or events such as the arrival of people to a terminal, known parameterized distributions suffice to provide an accurate model. Often, however, the events to be simulated do not conform to or are not known to behave according to computable distributions. For example, many economic and social systems often require complex mathematical and logical models to reflect their behavior accurately. In deriving these models researchers are often required to observe specific components of the system they wish to simulate.

Most classroom phenomena falls into the category of those systems which would require a period of observation before they can be accurately described. Existing classroom observation schemes, however, are generally concerned with the interactions which occur between participants in the instructional process [15, 25, 34]. To develop a model of instructional space use, however, information must be available which describes the number and configuration of participants in instructional activities and the physical equipment necessary for these activities. This information must then be organized by instructional program and translated into specific space requirements for activities operating under those programs. Although the classroom organization can be generally defined for different educational programs, the specificity of information required to build an accurate model for a simulation can be best derived from direct classroom observation.

2.2 Problems of Observation Schemes

There are many problems associated with non-mechanized recording schemes. These have to do with the interpretation of events by observers, the complexity of the systems being observed, the instrumentation used to record the observations, and the costs involved in administering an observation program.

The use of human observers places implicit limits on the accuracy and reliability of the data depending on the degree of bias of an observer and the amount of subjectivity involved in interpreting the events. These problems can be partially alleviated by rotating observers (to reduce the bias factor), comprehensive training of observers to reduce subjective judgments, and of course the design of observation methods which are as objective as possible.

With respect to the complexity of the system being observed, consider the observation of instructional activities for determining their impact on educational space.

Under the strictest interpretation of the traditional methodology, the activities in a closed classroom would be relatively easy to observe and record. Identity of events could be easily determined and the recording of other items such as the number of students and their configuration would also be straightforward. In addition, the rate of change of activities would be slow enough to allow observers time to make better decisions about questionable items.

Contrasting with this traditional model is the unstructured environment of an open school. Large spaces accommodating several simultaneous activities which are frequently changing are much more difficult to observe accurately. More than one observer can be assigned to such spaces, but the problems of coordination of observers then becomes a factor. The observation recording form must allow entries to be made as quickly as possible so that information will not be lost.

2.3 Method

The development of the observation procedure for this study was conducted by 1) determining what items of information about elementary school activities should be recorded, 2) designing observation forms appropriate to the task and 3) field testing and revising the procedure where necessary. Two schemes (Appendix A) were developed, field tested, and modified before the final version of the observation procedure was adopted.

Before deciding specific items of information to be recorded some overall goals had to be defined. The primary architectural description of interest was the requirement for and use of space by activities. The major component of an educational activity which requires space is the student; thus the focus of the observation procedure was on information which detailed how many students typically engaged in activities under a school program, what resources they used, and how much time they spent on the activity. Furthermore, the space in which an activity took place, its size, shape, and resources could be used to characterize activities in terms of the amount of space deemed necessary by experienced teachers in a given school program.

From the perspective of the activity, the resources are represented by a set of requirements for floor space, furniture, and equipment; whereas the space is expected to provide the required resources for the activity to be conducted in an efficient manner.

The observation procedure was to relate, for a given school, activities, students, spaces, resources and time in such a way as to allow the development of models of characteristics of activities which could be generated in a simulator. Schedules of these activities would also be generated which would reflect scheduling and grouping techniques employed under different methodologies.

An observer positioned in an instructional area would make entries upon an observation form which would describe the asynchronous events taking place over the course of a given school day. The result would be a scenario which would reflect the sequence and characteristics of activities through the "eyes" of the space in which they took place.

Because of time constraints, the requirement of formatted entries on the observation sheet and the large number of items to be recorded, the observation procedure was an intricate one and required capable, conscientious observers.

One major consideration in the design of the recording sheet used in the observation procedure was that over the course of a short period of time a given space might be the scene of many activities, a good number of which happen to occur simultaneously. It is important to maintain the distinction among simultaneous activities because they reflect the physical realization of the way students are being grouped to accomplish educational goals--hence can be viewed as a function of the methodology being employed at the observed school.

2.3.1 Determining the Pertinent Information Items*

The determination of those aspects of elementary school activities which were to be ovserved came about as the result of several school visitations and consultations with principals, teachers, school architects, and school administrators. Several schools in southern Wisconsin, including open-plan schools, were visited. Rooms and pods were observed at length, and careful attention was given to any characteristics of an activity which could conceivably be affected by or have an effect upon the physical constraints of the space in which it occurred and the actual utilization of the space.

Items which were chosen for inclusion on the final version of the observation forms were of two types: 1) those which were recorded once per day for each space observed and 2) those which were repeated for each observed event. Items of the first type were for identification and included the observer's name, the name and organization type of the school, the date of observation, and identification of the space for which the observer was responsible. Items of the second type were intended to provide information about space use in terms of the physical aspects of activities and in terms of the scheduling of groups meeting to pursue those activities. A list of the latter type items follows with an explanation of each item and the reasons for including it on the final observation form. For convenience, the items are presented in the same order as they appear on the form in Figure 2-1.

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*This was done with the assistance of Mr. Michael Even, an architect and former research associate at the U. of Wisconsin.

Item Name or Description	Explanation
1. Start and End Time	The start and end time for each event was recorded for the purpose of providing information about the scheduling of activities. Information to be derived included duration and sequence of events plus data concerning the time of day certain activities were likely to take place.
2. Location	Location of an activity identified the subspace of a space[*] in which the activity was taking place. Keyed to a scale drawing of the space and its subspaces, the total floor space being used by the activity could be determined.

---

[*] Note a subspace s of a space S is formally defined as $s \subseteq S$ which means that it is possible that $s = S$; e.g., a space may be a subspace of itself.

3.	Group	A name was assigned to each group as it formed to partake in an activity. Whenever the same group could be identified at another time, its assigned name was to be used. This item was to provide information pertaining to the circulation of groups within an observed space.
4.	Group Type	Group type showed whether a group of students were proceeeding independently or as a group in pursuing their activity. This characterizer would have an effect on the decision of what space the group would be assigned during the simulation procedure.
5.	Number of Students	The number of students in each group observed was recorded to provide information which could relate educational program grouping practices for instructional activities. The number of students in an activity is an important factor in computing the space required for the activity.
6.	Number of Supervisory Personnel	The number of teachers and teacher aides was recorded since the additional people concerned with the activity require additional space. Supervisory personnel were differential from the students in the activity to document methodological differences in staffing.
7.	Name of the Event	The events recorded were of two kinds, each of which could be represented by a different model. The two kinds of events were 1) subject or instructional type events, and 2) other events,

	which attempted to describe circulation, changes in the make-up of a group, and unused space. For a complete listing of event codes see Appendix .
8. Physical Configuration of the Group	The physical configuration of a group refers to the arrangement of that group in a space. How the group is arranged can affect how much space is used. A description of configuration types is given in Table 2-1.
9. Distraction Factor	The distraction factor was defined as a composite index of the amount of noise and physical activity associated with an instructional activity. The purpose of the distraction factor was to determine the potential for one activity to disturb another if they were held in adjacent spaces with no intervening walls. When assigning spaces to activities in the simulation, the distraction factor should have an effect on the location of activities relative to one another.
10. Furniture and Equipment	All the furniture and equipment employed in conducting an activity was recorded. Different pieces of furniture require different amounts of space, and activities could have certain regular requirements for furniture or equipment which, in the simulation, would affect the decision on what space would meet those requirements best.

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Figure 2-1
SAMPLE OBSERVATION FORM

Page ______

Observer: ______________________

Date: ______________________

School: ______________________

Space: ______________________

LINE	TIME		LOC	GRP	GT	#S	#T	EVENT	BASIC CONFIG.	DF	#CH	#DE	#TA	#TD	OTHER EQUIPMENT							
	START	END																				
01																						
02																						
03																						
04																						
05																						
06																						
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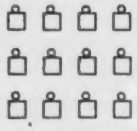
TABLE 2-1

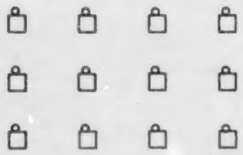
CONFIGURATION CATEGORIES*

1. Frontal Minimal (FMI)--Students arranged rectangularly, in rows with aisles between rows.



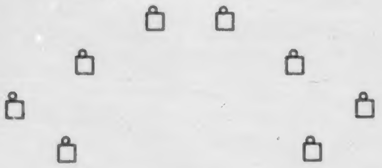
Frontal minimal configuration

2. Frontal Optimal (FOP)--Students arranged rectangularly, in rows with aisel space on all sides of each student.



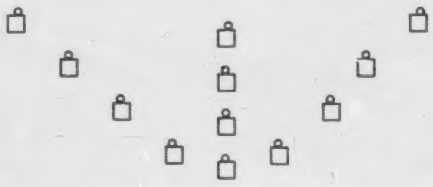
Frontal optimal configuration

3. Circular (CRI)--Students arranged in a circle or arc.



Circular configuration

4. Radial (RAD)--Students grouped in lines radiating from a common center.



Radial configuration

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*Configuration categories were determined by Michael Even.

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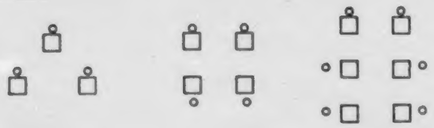
TABLE 2-1

(Continued)

5. Clustered (CLU)--Students scattered in small groups.



Clustered configuration

2.4 Design of the Observation Forms

The observation forms were designed so that the recorded data could be directly transferred to punched cards, yet be conveniently transcribed with a minimum of decision making on the part of the observer.

Three kinds of data were recorded; quantitative (e.g., group size), categorical (e.g., subject) in which items could be chosen from a list, and graphic (scale drawings of observed spaces and subspaces).

The quantitative and categorical items were designed to be entries on an 8½" x 11" observation sheet (Figure 2-1), one column for each entry. Each observation of an event could thus be described on one line of the sheet. When several events or activities were observed to occur simultaneously, their start-times could quickly be recorded on consecutive lines, the other descriptive entries made, and the end times easily filled in when the activity was observed to end.

To conserve recording space, lists of categorical items were drawn up and appropriate codes were assigned to them for use by the observer. The categorical items included Event, Configuration, and Other Equipment, and schedules of these items are presented in Appendix which contains the directions and reference sheets given to each observer.

The graphic data consisted of a floorplan of the space in which an observer was to be stationed. On the floorplan the observer would draw and name (to be keyed to the observation sheet) each subspace in which a recorded event took place. The space and subspace drawings were later transferred to punched cards through the use of a digitizer in the Cartography Department at the University of Wisconsin.

2.5 Selection of Sample Schools

Two types of elementary school programs were observed--the traditional program where one teacher ran a self-contained classroom of from 20-40 students, and the multiunit program where teams of 4-5 teachers worked with units of 150-200 students.

Three schools were selected for observation, two of which were multiunit (Schools A and B), the other, traditional (School C). Because of the recent trend in building open plan or pod-type schools without interior walls, the two multiunit schools selected were of the open plan type (see floorplans, Figures 2-2 and 2-3). Classrooms in School C were rectangular with dimensions of 22' x 35' or 27' x 29'.

All of the spaces observed at Schools A, B, and C were instructional areas ranging over grades 1-6. In School A, the three units observed represented the equivalent of grades 1-3, 3-5, and 4-6 for units 2, 3, and 4 respectively. In School B, only the units representing grades 3-5 (area A) and 4-6 (area B) were observed. In the traditional school, C, classrooms were observed for grades 1-5. Two weeks of observation was done at School B (the first of which served to acclimate the observers, not all of whom were available each day) and one week of

FLOORPLAN OF OBSERVED UNITS
SCHOOL A

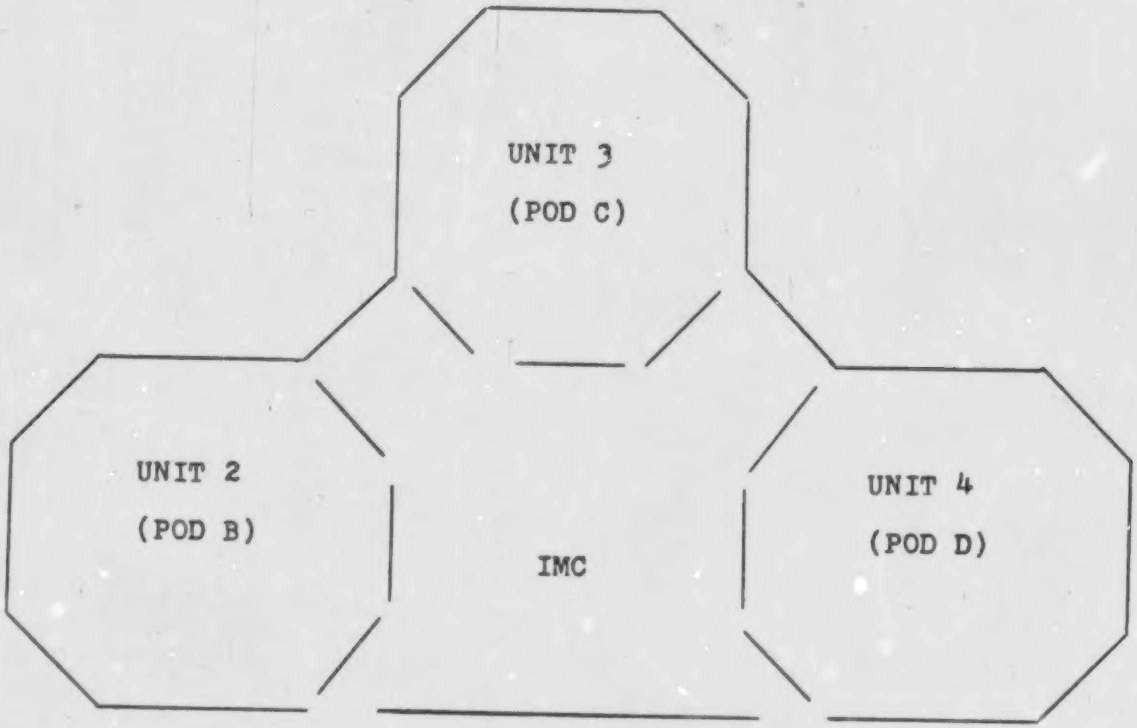

UNIT 3
(POD C)
UNIT 2
(POD B)
IMC
UNIT 4
(POD D)

Figure 2-2

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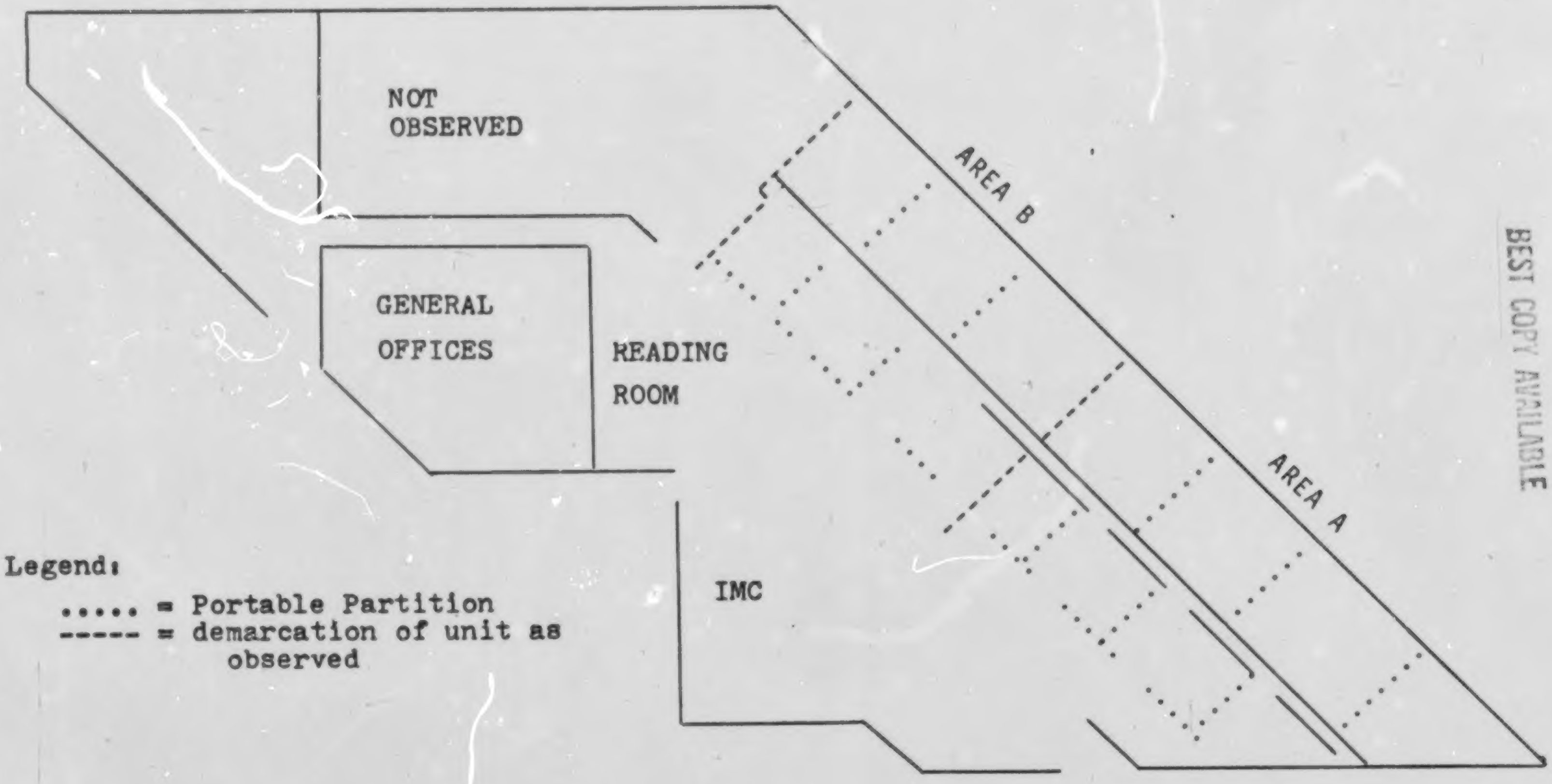
FLOORPLAN OF OBSERVED UNITS
SCHOOL B


NOT OBSERVED
GENERAL OFFICES
READING ROOM
IMC
AREA B
AREA A

Legend:
..... = Portable Partition
----- = demarcation of unit as observed

Figure 2-3

observation was made at each of Schools A and C. The actual time spent in each space at School C was dependent on the decision of the individual teacher as to how long her classroom could be observed.

The operation of the multiunit schools was based on individual unit schedules which allocated blocks of time for general subject areas. For example, the first 30 minutes of every morning at School A, unit 4 was scheduled for language arts activities. At School C, the traditional school, the classrooms each operated on their own specific schedule with more specific activities designated at each time period. A sample schedule for School A, unit 4 is shown in Table 2-1. The length of the scheduling cycle at all three schools was one week; the only daily changes were those representing accommodations made for physical education, art, and music.

It should also be noted that School B was in a transition phase from a traditionally operated school to a multiunit school. Hence, there was a tendency for organizing spaces and groups more on the order of the self-contained classroom than might otherwise have been expected.

TABLE 2-2

SAMPLE SCHEDULE FOR SCHOOL A, UNIT 4

8:30	Language Arts Block		
		9:00- 9:30	Physical Education-Group 1*
		9:30-10:00	Physical Education-Group 2
10:30	Math Block		
11:30	Lunch Hour		
12:30	Study Hall		
		12:30-1:00	Music Group
		12:30-1:00	Physical Education Group
		12:30-1:00	Art Group
1:00	Math Block		
2:00	Recess		
2:15	Language Arts Block		
3:15	End of Day		

---

*Entries in the second column represent activities which take place outside of the observed space but do not involve all the students. Those students which remain in the space continue the activities in column 1. When an activity in column 2 is completed, the group returns and continues the activity specified in column 1.

2.6 Collection of the Data

The actual collection of data was performed at the three schools from April 10, 1972 to May 5, 1972 for the periods of time described earlier.

2.6.1 Orientation of the Observers

Five observers were hired, only three or four of whom worked at any one time. Each day observers were assigned a space and given their materials. The materials consisted of observation sheets, instructions (including lists of categorical items with their codes) and a floorplan. The instructions appear in Appendix B. Prior to the first live observation, a training session was held with each observer and his or her part in the project was explained in detail. The first week of observation was utilized to get the observers accustomed to live recording of data and to resolve problems in the observation procedure. The reliability of the observers was thus established through careful monitoring of the early observation results.

2.6.2 Assignment of Observers to Spaces

There were two considerations involved in assigning observers to spaces: 1) how many observers were necessary for a single instructional area and 2) how to avoid or reduce possible bias on the part of the observer in recording information.

In the former case, it appeared that for traditional closed classrooms, a single observer could easily dispatch his or her responsibility. The multiunit school, A, with its large pods and often changing groupings of students was significantly more challenging. Recording the activities of more than 150 students instead of about 30 seemed to be beyond what could be reasonably expected from observers. The space itself was large enough so that one could not get accurate counts of students and equipment when positioned across the room.

The availability of one extra observer during the week the study was taking place at School A provided an opportunity to place two observers in one of the three pods being watched, each of whom was assigned one-half of the area. Upon inspection, the observations appeared to be more accurate and with greater detail than those of a single observer in the same pod. Thus it was concluded that for large spaces, more than one observer was desirable.

To reduce bias the observers were rotated among spaces observed on a daily basis. No formal analysis was made to verify the existence or absence of bias, but spot checks of observers' forms--especially with respect to their perceptions and drawings of subspaces within the observation area--showed a general consistency in their recording of data.

2.7 Discussion

Since the study was interested in the physical aspects of activities, attention was focused on those events which would be considered instructional entities or those which represented the dynamics of groups. The group dynamics data included descriptors of formation of a group and subsequent coalescing into a larger group or the splitting into subgroups. Furthermore, items denoting circulation within spaces and between spaces were recorded in an attempt to discover patterns of circulation, especially for open plan schools.

The data collection phase yielded about 3000 lines of observations. The data, however were not as readily adaptable to computer analysis as had originally been thought. Some of the difficulties were due to the constraints of the observation form itself; some to the transformations which had to be performed on the data before it was acceptable to the computer analysis programs, and some to the latitude given to the observers which resulted in either inconsistent or uninterpretable data.

Because an event could be described on one line, events starting simultaneously, such as a large group breaking up into several separate groups and starting independent activities, could be recorded on consecutive lines without confusing the observer or the analysis procedure.

Items on the sheet were arranged so that similar or related items were grouped together (e.g., Group, Group Type, Number of Students, Supervisory Personnel and all the Furniture and Equipment items). In addition, the most dynamic information was located on the left side of the sheet so that it would be recorded immediately--namely, time of the event. It should be further noted that the most common furniture items, chairs, desks, tables, and teacher's desks, were made column headings so only their quantities had to be entered.

Of the data items recorded per line of observation, there was little difficulty encountered in the recording of time, group size, supervisory personnel, distraction factor and the four pre-labelled furniture columns. Certain kinds of events, configuration codes, and the recording of other equipment did present some problems in reliability, however.

Circulation events and minor changes in the makeup of groups were difficult to record accurately in addition to the major activity events. Appending furniture and density designators to the configuration codes proved to be confusing to observers.

One further problem in recording was evident in that very few observations were recorded in the Other Equipment column; and what was recorded tended to decrease as the days progressed.

The aforementioned problems were at most nettlesome and were not of sufficient import to affect the overall objective of the observation procedure--to provide data for modelling activities under differing educational methodologies. In fact, the approximately 950 observations of instructional activity events alone provided a sufficient base for testing various aspects of the simulation program. Furthermore, the instructional activities were recorded as a set of sequential states from which it would be possible to infer some of the circulation information; the graphic information combined with inventories of furniture and group sizes would allow the configuration density to be deduced; and the obvious equipment requirements for activities (such as the likelihood of using a piano in a music activity) could be arbitrarily defined.

One further problem occurred because observers were allowed to generate their own names for locations which they were observing. Since the observers were rotated among spaces in a school, the same spaces and its subspaces were renamed several times, thus requiring a good deal of effort to rename each space and subspace consistently to allow a computer analysis of space use in the observed schools.

2.8 Recommendations

With a few alterations, the forms described are adequate for recording observations of elementary school instructional activities. A different approach will be necessary to observe and record circulation and group dynamics directly. The precise approach would depend on the particular inferences which could be drawn from the instructional activities about circulation and group dynamics in the observed elementary schools.

Alterations to the observation forms would include:

Pre-assignment of names to all spaces and subspaces observed (the observers were allowed to generate their own names).

Deletion of the density codes since they can be computed from information already present on the form.

Elimination of group names (the observers cannot keep track of the content of groups).

Dropping the event codes designating circulation and group dynamics information.

Replacing the "Other Equipment" columns with prelabelled columns specifying particular pieces of equipment to record. Such equipment would include TV sets, movie projectors and similar items which could be determined to affect space use.

The above alterations would eliminate the major sources of confusion (names of subspaces and groups), reduce subjectivity on the part of the observer from having to decide density, and make the recording of furniture and equipment more efficient. Of course, adoption of a new version of the observation form would be contingent on an appropriate field test.

2.9 Conclusion

This chapter has described the derivation and construction of an observation procedure to collect data about the physical aspects of elementary school activities. With some improvements, the procedure is thought to be a viable means for obtaining data which, when used appropriately, can supply information for use in the development and evaluation of school floorplans. A test of the procedure on three sample schools yielded a sufficient amount of usable data to warrant this conclusion. The next chapter uses this data to develop a procedure for building models of educational activities which would reflect the observed activities for differing school programs.

CHAPTER 3

Data Analysis and Results

3.1 Introduction

This chapter describes the analytical procedures which were applied to data collected during the observation phase and summarizes the results. The objective in analyzing the data was to derive the basis for a model of educational activities.

The model consists of a set of frequency distributions compiled from the observed data and algorithms which operate upon those distributions to generate schedules of activities, distributions of students among them, and a selection of physical characteristics which would affect the choice and use of space.

Given a schedule and an initial student population, the objective of the simulation program is to generate those subactivities which are likely to occur during a block of time. Two factors are necessary to determine such a schedule--the number of students engaged in a subactivity and the duration of each subactivity. The actual algorithm used to generate schedules of subactivities is described in Chapter 4. In the following sections of this chapter models for predicting group size and activity duration are developed and their relationship to each other is examined. The remainder of the chapter describes the modeling of the physical aspects of activities. The information for these models was obtained from the observations described in Chapter 2.

The other observed characteristics of activities were compiled into tables of information referred to as activity descriptors. These characteristics included the physical configuration of students in a space, furniture and special equipment used, the type of group pursuing the activity, and a composite noise/physical activity indicator called the distraction factor.

From the configuration and furniture requirements the amount of square feet per student required for an activity can be computed; this figure multiplied by the projected group size yields the total square feet required for an activity. Furthermore, a relationship between activities can be determined as a function of the distraction factor and can be used in deciding upon the actual placement of activities in a space.

It should be noted that as an exploratory study, the results presented herein should be interpreted from the perspective of the methodology used to derive them rather than as design parameters per se. This is due to the sample size for schools which was too small to provide a reliable data base.

Because the major focus of the study was the multiunit school, and the most consistent data was recorded at School A which was using the multiunit plan, a complete analysis of this school was run from which to derive a useable simulation model. Comparisons were made and are reported on all three schools, however, where the quality of the data allowed such an analysis to be done.

3.2 Developing Models of Activities, Group Sizes and Durations

3.2.1 Introduction

Standard analysis of variance procedures were applied to the collected data to determine major factors contributing to the sizes of groups and the duration of instructional activities. Frequency distributions for appropriate categories of group size and duration were then generated for each of the significant factors found in the analysis of variance and thus represented the computational model utilized in the simulation. A Pearson χ^2 test of statistical independence was performed on group size and duration to verify that the distributions could be used to generate these properties of activities independently. from one another.

In each statistical test the level of significance was established at $p < .001$. This conservative level was chosen to minimize the chances of incurring a Type 1 error--rejecting the null hypothesis falsely.

3.2.2 Establishing the Statistical Independence of Group Size and Duration

Before the derived models of group size and duration could be used together to simulate schedules of subactivities, their statistical independence had to be ascertained. If the two variables were unrelated, they could be generated from their derived distributions independently. If they were not independent, however, a joint frequency distribution would be necessary to model them.

A Pearson χ^2 test of association performed on the joint frequency distribution of categories of observed group sizes and durations (see Table 3-1), showed that the two variables were not significantly related ($d.f.=54$, $\chi^2=49.85$, $P > .655$).

3.2.3 Developing a Predictive Model of Group Size

To develop a predictive model of group size, an analysis of variance was performed to discover from which other factors there were significant effects.

The hypotheses tested were that school program, instructional activity, and age would have significant effects upon the size of groups.

Factors considered in the analysis were School (2 levels), Activity (4 levels), and Age (that is, Pod) (3 levels). Although School B was designed as a multiunit

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TABLE 3-1

JOINT FREQUENCY DISTRIBUTION OF CATEGORIES OF GROUP SIZE AND DURATION

Group Size

Duration In Minutes

	1-6	7-16	17-35	36-300	Total	% of Column
5	38	31	29	14	112	11.2
6-10	47	28	44	10	129	12.0
11-15	63	38	47	9	157	15.7
16-20	38	45	28	7	118	11.8
21-25	25	25	31	11	92	9.2
26-30	34	37	50	11	132	13.2
31-35	27	15	24	8	74	7.4
36-42	17	16	23	0	56	5.6
41-45	10	11	19	1	41	4.1
46-50	7	7	5	0	19	1.9
51-55	0	4	7	0	11	1.1
56-60	8	10	11	1	30	3.0
61-65	0	1	4	0	5	0.5
66-70	2	2	1	0	5	0.5
71-75	0	5	3	0	8	0.8
76-80	1	0	1	0	2	0.2
81-85	0	0	3	0	3	0.3
86-90	1	1	0	0	2	0.2
91-95	1	0	2	0	3	0.3
TOTAL	319	276	332	72	999	

CHI-SQUARE = 49.85 with 54 DF.

Probability (CHI-SQUARE > 49.85) = .6553 school, it was in a transitional phase and still operating as a traditional school with some amount of teaming. Therefore, Schools B andC were considered to be traditional schools and School A a multiunit school. Activities were originally classed as Language Arts, Math, Science, Art, Music, Social Science and Other (consisting mainly of independent work). However, Art and Music were generally carried on in special rooms which were not observed, while Social Science occurred only occasionally, but not in conjunction with all levels of the other factors. Therefore, Art and Music were not included in the analysis and the small number of Social Science observations were included in the "Other" category. The variable Pod corresponded to a unit in a multiunit school and served to bracket grade and age levels. The three levels in terms of school grade were 1-2, 2-4, and 4-6. There was an obvious difficulty in attempting to compare these units with the more rigidly defined grade level in the traditional school. It was decided that the best comparison could be made by breaking the traditional school into three units consisting of grade 1, grades 2 and 3, and grades 4 and 5..

Analysis of variance of group size revealed significant main effects ($p < .001$) for school program ($F(1,\infty) = 33.07$), activity ($F(3,\infty) = 13.41$), and the interaction of school and activity $(F(3,\infty) = 6.32)$. Table 3-2 presents a summary of the analysis.

The interaction effect indicated that group size could only be generated as a function of the values of the School and Activity factors, as opposed to just school alone.

Over all schools, (see histogram, Figure 3-1) the observed frequency of group size decreased with increasing size. Furthermore, a reasonable categorization of group sizes into "small", "medium", "large", and "very large" could be made for groups ranging in size from 1-6, 7-16, 17-35, and 35+.

For the particular model of School A, the observed group sizes were categorized into the four levels and a frequency table for each Activity was tabulated (see Table 3-3). These categories were further justified upon an examination of the mean group size at each level which fell nearly in the center of each grouping. In addition, the distributions of group size within the category limits were relatively flat (save for the peaks at multiples of 5).

Thus, a group size g for an activity can be chosen by the following method. Let C_i, $i=1,4$ designate the four categories of group size with category limits L_i and U_i for the lower and upper limits respectively. Let

TABLE 3-2

SUMMARY OF VARIANCE ESTIMATES, ERROR TERMS, AND F-RATIOS FOR SIGNIFICANT SOURCES IN THE ANALYSIS OF VARIANCE OF GROUP SIZE

Source	df	MS	F-Ratio
School	1	19856.16	33.07*
Activity	3	8053.09	13.41*
Pod (age)	2	4115.09	6.85
School x Activity	3	3796.12	6.32 *
School x Pod	2	1545.77	2.57
Activity x Pod	6	922.47	1.54
School x Activity x Pod	6	1448.57	2.41
Within Cells	898	600.4056	

*$p < .001$

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Percent of Observed Frequency of Group Sizes

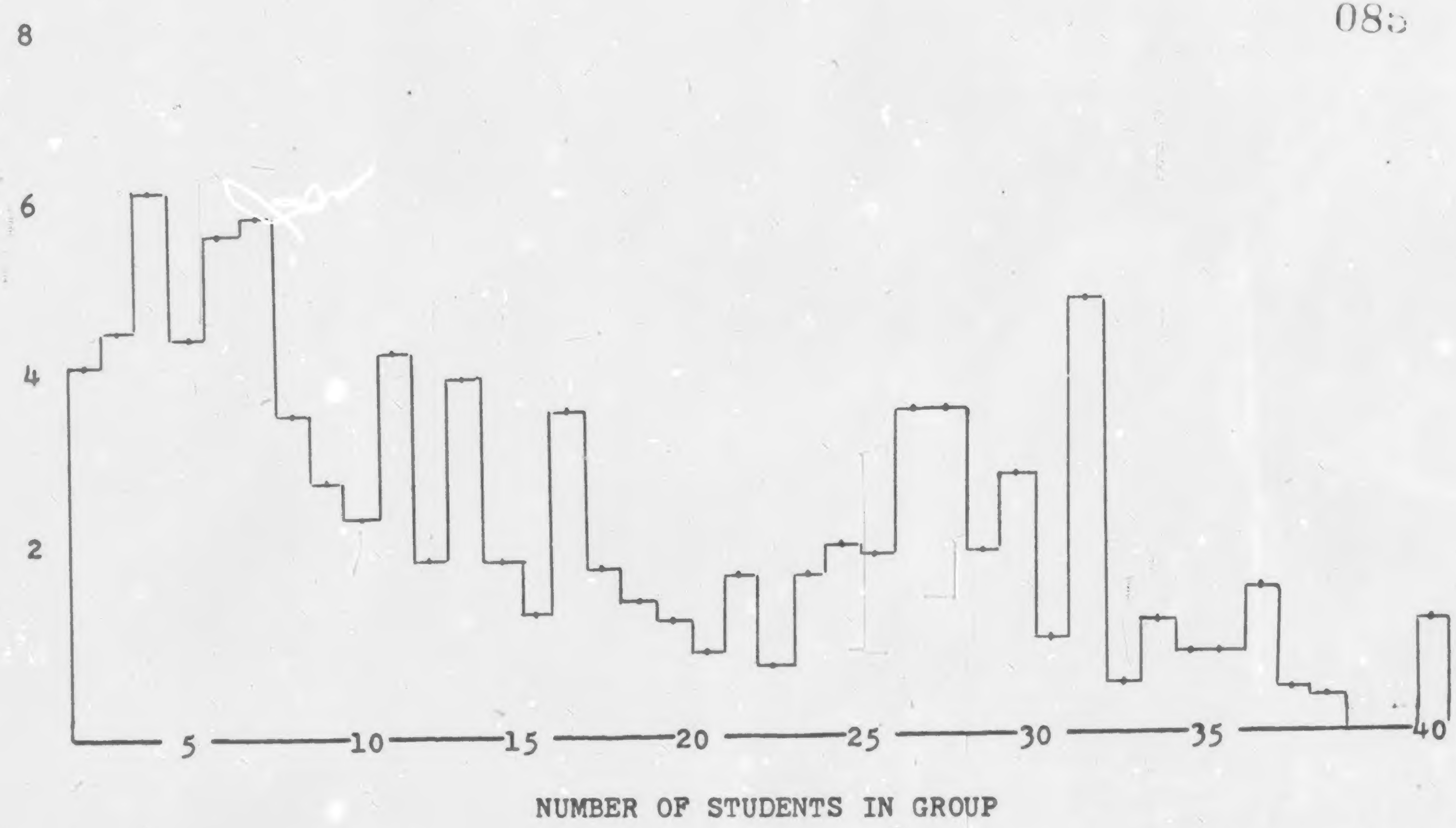

Figure 3-1

TABLE 3-3
OBSERVED FREQUENCIES OF GROUP SIZE/ACTIVITY FOR SCHOOL A

GROUP SIZE		ACTIVITY*				
		ART	LANGUAGE ARTS	MATH	SCIENCE	OTHER
1-6	Count	11	82	13	3	11
	% Col	25.00	40.00	33.33	5.26	13.25
	Mean Groupsize	3.6	3.6	4.1	3.6	3.75
7-16	Count	8	70	8	14	17
	% Col	18.18	34.15	20.51	24.56	20.48
	Mean Groupsize	12.5	11.4	11.3	10.3	10.7
17-35	Count	15	43	12	33	22
	% Col	34.09	20.98	30.77	57.89	26.51
	Mean Groupsize	28.09	25.2	24.1	25.8	24.0
35+	Count	10	10	6	7	33
	% Col	22.73	4.88	15.38	12.28	39.76
	Mean Groupsize	52.9	96.2	46.0	106.3	96.4

---

*Enough observations of art were made at School A to be included in the table.

p_i stand for the observed percentage of observations for which the group size fell into C_i. An activity is first assigned a group size category with probability $P(C_i) = p_i$. Within the category, the distribution of group sizes is assumed to be even, hence an evenly distributed random number from L_i to U_i is chosen to be G, the group size.

The reader may observe that the above computation is equivalent to choosing a group size from a table which lists each possible group size value and its corresponding probability. Within the range of a defined category C_i the probability of choosing any particular group size would be $\frac{p_i}{U_i - L_i}$. The two level computation, however, requires less preparation and computer storage.

3.2.4 Developing a Predictive Model of Activity Duration

Utilizing the same general technique as was used in developing a model for group size, a predictive model for the duration of an activity was derived by determining whether there were significant effects upon duration from other observed factors.

The first question tested was whether activity duration varied with school program and instructional activity.

As in the analysis above, Schools B and C were treated as traditional schools and School A as a multiunit school. Activities consisted of Language Arts, Math, Science, and Other which included all other instructional activities.

An analysis of variance on the observation data in a 2 x 4 design (school program x activity) showed no significant effects $(p > .001)$ for school program, $(F(1,\infty) = 1.47)$, activity $(F(3,\infty) = 4.63)$ or school x activity $(F(3,\infty) = 3.60)$.

Since neither school nor activity was found to be a significant factor, observations were collapsed across both of these factors in developing the model for duration. Over all activities and all schools, a histogram (Figure 3-2) shows that the distribution of observed durations is skewed with a peak between 15-20 minutes and a smaller peak at 30-35 minutes. The five minute interval was chosen because upon examination of a minute by minute tabulation, most events were recorded as taking place at a time equal to an integral multiple of 5. Whether this was due to an unconscious rounding off process by the observer or reflected a propensity for activities to begin and end at "even" times (five minute integrals) is not known. The peaks in the distribution at 15-20 and 30-35 would seem to indicate that for the schools involved, a

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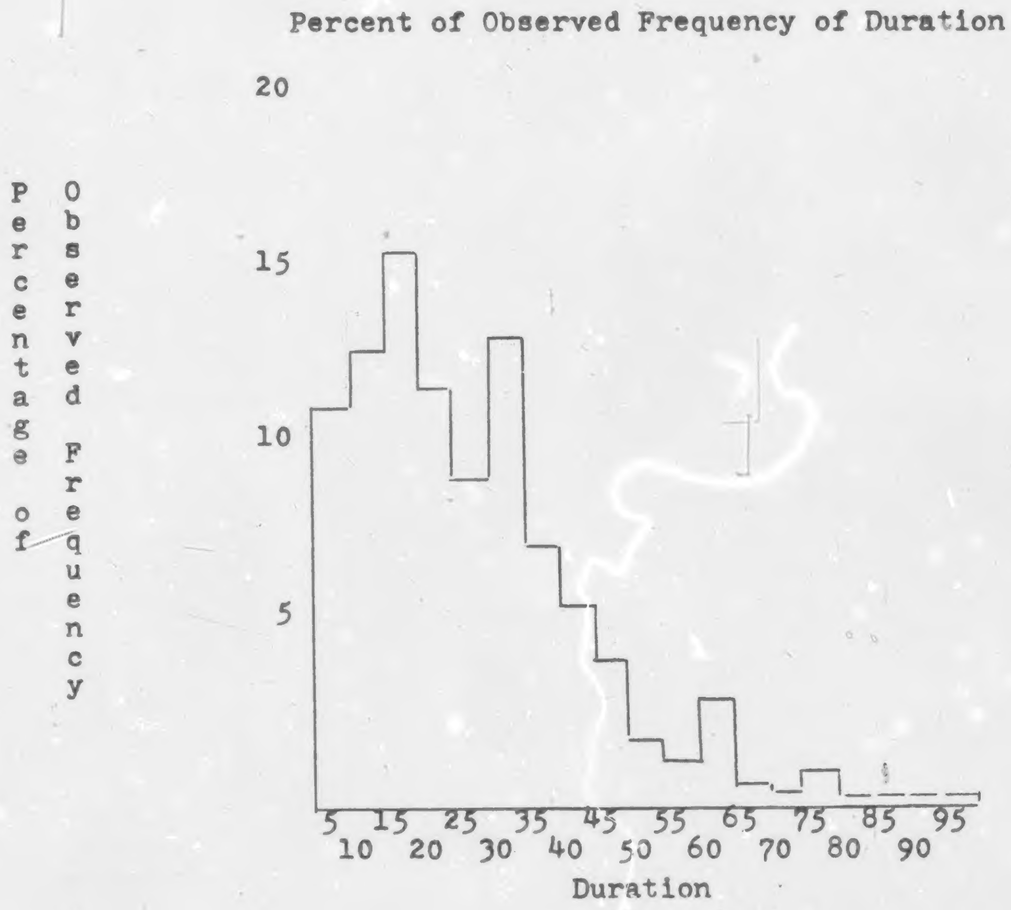

Figure 3-2

reasonable time for an activity might have been 15 or 30 minutes. The rapid falloff of observations of activities taking longer than 30 minutes could, perhaps, be attributed to limits on the length of the attention span of an elementary school age child.

Consideration of the possibility that the duration of an activity might be different for younger and older students led to an analysis of the effects of age upon duration. For this test, POD was used as the factor since the pods divided the students into three age levels; 6-8, 8-10, and 10-12. A one-way analysis of variance for three levels of pod showed no significant effects $(F(2,\infty) = .33,\ p > .001)$.

A predictive model of duration was therefore constructed from the distribution of observed activity durations across school, activity, and pod. This distribution is summarized in the percentage column of Table 3-1. To obtain the duration of an activity let C_i $(i=1,20)$ designate any one of the 20 categories of duration with category limits L_i and U_i respectively. Let p_i stand for the observed percentage of observations for which the duration was of a length falling in C_i . An activity is first assigned a duration category with probability $P(C_i) = p_i$. (The lower bounds of the intervals for the duration of the activity are chosen to correspond with the apparent tendency for activities to last for integrals of five minutes.) Within the category the distribution of durations is assumed to be uniform, hence a uniformly distributed random number from L_i to U_i is chosen to be D, the duration.

3.2.5 Discussion

A method has been presented for deriving estimates of the group size and duration of activities under specified elementary school programs. The method consists of determining which of several hypothesized factors affected group size and duration by an application of analysis of variance. For each of the dependent variables group size and duration, separate analysis of variance were performed for school program, activity, and pod (grade range). For the schools observed, the school program and activity were found to have significant effects on group size; while duration did not appear to vary significantly for any of the three.

Frequency distributions of group size as a function of school and activity, and of duration for all observations were then plotted. Neither conformed exactly to known theoretical distributions, hence suitable categories were chosen and frequency tables were generated for modeling the two variables. A final test was made on the two variables which ascertained that for the observed data, group size and duration were statistically independent. Thus the models described were incorporated into the simulation.

3.3 Creating Activity Descriptors

Once a schedule of activities has been generated from the models of group size and duration, each activity in the schedule can be characterized in terms of the particular use it will make of a space. The data used in making this characterization are referred to as activity descriptors which provide information about four major aspects of an activity:

1. The amount of space needed per student for an activity
2. The nature of the activity (group or independent, supervised or unsupervised)
3. The distraction potential of an activity upon other activities
4. The resource requirements of an activity in terms of equipment and furniture needs.

Each of these items is a factor which must be considered when deciding where a scheduled activity will be placed. The observation procedure is designed to collect information about these items either directly, as in 2, 3, and 4 or indirectly, as in 1, where observed space per student can be computed by dividing the area of the space identified in the "location" field of the observation form by the number of students recorded in the group size field. It should be pointed out, however, that as the actual data collection phase of this project produced an unsatisfactory set of observations in the Other Equipment category, estimates were used to provide data to the simulator for "resource requirements" items. The following sections detail the data reduction techniques and derive the models for each of the four aspects of activities mentioned previously.

3.3.1 Determining Space Requirements

Two approaches to determining space per student were employed. The first involved utilizing the observations made of how space was actually used in the different observed schools for different activities. Because of the difficulty in the recording of furniture used for an activity, the configuration of students, irrespective of the actual furniture used, was examined and related to the use of space. The second approach involved the derivation of optimal space per student needs based on estimated dimensions of furniture and aisle space under the different configurations.

3.3.1.1 Observed Space Per Student

To test school designs in situations reflecting the observed management of instructional space, a model was derived from observed frequencies of the five kinds of configurations described in Chapter 2, Section 2.3.1.

The frequencies are reported in Table 3-4 for the three observed schools. The most notable apparent differences were the negligible use of the frontal optimal configuration and the dominance of the clustered configuration in school A.

A model of observed space per student was developed for school A by preparing for each of the configuration types, a table showing the frequency of observed square feet per student for four configurations (Table 3-5). The categories of square feet per student were chosen from inspection of a histogram (Figure 3-3) in which observed frequency of square feet per student at school A was plotted at intervals of two square feet. Reasonable categories can be derived from the histogram with ranges 3-12, 13-40, 41-58, 59-100, and 100+, within which the frequencies are fairly uniformly distributed.

Simulating observed student space needs consists of two operations. First a configuration, CON_j, $(j=1,...,4)$ is chosen for an activity according to the distribution of observations shown in Table 3-6. Let C_i, $(i=1,2,...,5)$ represent the five categories of observed square feet per student for configuration CON_j with lower and upper limits L_2 and I_u, respectively. Let p_i, $(i=1,...,4)$ equal the percentage of observations for which observed square

TABLE 3-4

FREQUENCIES OF OBSERVED CONFIGURATION* BY SCHOOL

		School		
		A	B	C
Configuration	FMI	37	36	12
	FOP	2	82	30
	CIR	93	76	79
	CLU	249	137	97
	RAD	25	0	0

*Configurations are:

FMI - Frontal Minimal
FOP - Frontal Optimal
CIR - Circular
CLU - Clustered
RAD - Radial

For complete description see Chapter 2, Table 2-1.

TABLE 3-5

FREQUENCY OF OBSERVED SQUARE FEET PER STUDENT FOR FOUR CONFIGURATIONS-SCHOOL A

		Configuration				
		FMI	CIR	CLU	RAP	
Square Feet Per Student	0-12	17 45.95	23 24.73	59 23.69	0 0.0	COUNT % of Column
	13-40	16 43.24	35 37.63	66 26.51	6 24.50	COUNT % of Column
	41-58	4 10.81	11 11.83	30 12.05	8 36.00	COUNT % of Column
	59-99	0 0.0	9 9.68	21 8.43	4 16.00	COUNT % of Column
	100 +	0 0.0	15 16.13	73 29.32	6 24.00	COUNT % of Column

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OBSERVED FREQUENCY OF SQUARE FEET PER STUDENT

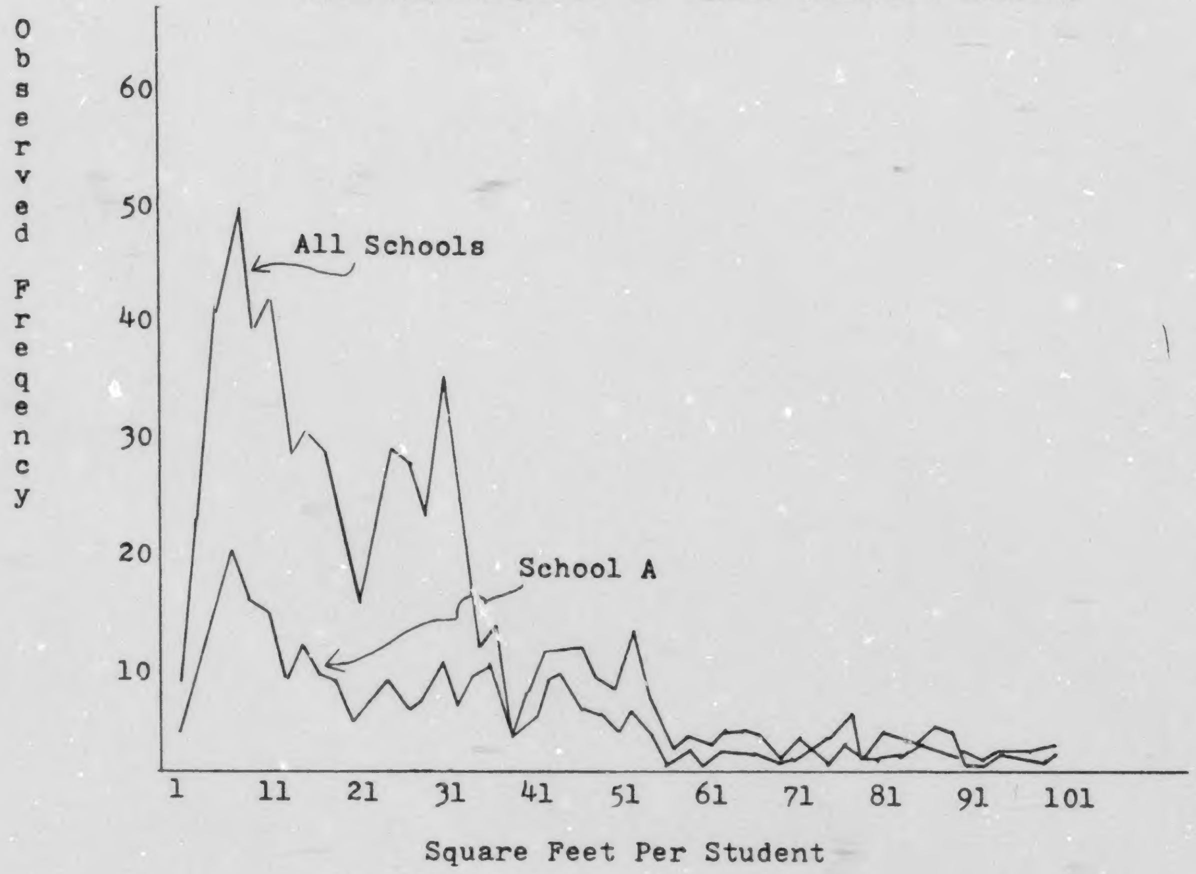

Figure 3-3

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TABLE 3-6

FREQUENCIES AND PERCENTAGES OF OBSERVED CONFIGURATIONS - SCHOOL A

Configurations*	Frequency	Percent of Observed Frequency
FMI	37	9.1
FOP	2	.49
CIR	93	22.9
RAD	25	6.6
CLU	249	61.3

*Configurations are:

FMI - Frontal Minimal

FOP - Frontal Optimal

CIR - Circular

RAD - Radial

CLU - Clustered

A detailed description of configurations is given in Chapter 2, Table 2-1.

feet per student fall into category C_i . A configuration is first assigned a square feet per student category with probability $P(C_i) = p_i$ within the category, the distribution of square feet per student is assumed to be uniform, hence, a uniformly distributed random number from L_i to U_i is chosen to represent square feet per student.

It should be noted that the observed space use figures should be interpreted with some caution. In the large, open spaces of school A, observations were made of as few as 7 or 8 students occupying an entire pod (approximately 7200 square feet of space). This reflects a misinterpretation on the part of the observer of how much space was actually being used. Obviously, this would yield an extraordinarily high space per student figure. Thus, in the data base supplied to the simulation program, an upper limit of 150 square feet per student was established to avoid generating an unrealistic space per student figure for a given activity.

It is still possible to generate unrealistic space needs, however, and so the use of observed space use figures is not recommended.

3.3.1.2 Optimal Space Per Student

An alternate method for modeling required space per student was developed for the purpose of providing more consistent information to school designers about space requirements. The optimal space figures are based on the dimensions of furniture in an activity, a scaled representation of each type of furniture into one of the five configurations, and the measurement of space used therein.

Four furniture items were considered in the model and their dimensions computed on a per student basis (Table 3-7A). These items were chairs, desks (including chairs), tables (including chairs) and a no furniture designation, since many observations were made of students arranged in configurations on floors in front of blackboards or around some area of interest but using no furniture. Added to these dimensions were figures representing computed aisle or circulation space associated with each of the configurations (Table 3-7B). For the radial and circular configurations, estimates of the circulation space required per student were based on scale drawings.

In Table 3-8 the computed optimal square feet per student figures are presented. For the FMI, FOP, and CLU configurations, the computation of square feet was as follows:

$$\text{SQ. FT.} = (F_L+A_F) \cdot (F_W+A_S)$$

TABLE 3-7A

OPTIMUM DIMENSIONS

Dimensions of Furntiure Items Used on Per Student Basic

		Length	Width
1.	Desk (including chair)	3 ft.	2 ft.
2.	Chair only	2 ft.	2 ft.
3.	Table (including chairs)	2 ft.	4 ft.
4.	No furniture	2 ft.	1.5 ft.

TABLE 3-7B

Aisle Space or Circulation Space Per Configuration*
Per Student

		Front	Side	Square Ft. Estimate
1.	FMI	2 ft.	--	
2.	FOP	2 ft.	2 ft.	
3.	RAD	--	--	18 sq. ft.*
4.	CIR	--	--	16 sq. ft.*
5.	CLU (assuming 4 desks per cluster)	4 ft.	4 ft.	

---

*Configurations are: FMI - Frontal Minimal
FOP - Frontal Optimal
CIR - Circular
CLU - Clustered
RAD - Radial

For complete description see Chapter 2, Table 2-1.

TABLE 3-8

COMPUTED OPTIMAL SQUARE FEET PER STUDENT

	Configuration	FMI	FOP	RAD	CIR	CLU
Furniture	Desk	10	20	24	22	42
	Chair	8	16	22	20	36
	Table	16	32	26	24	48
	No Furniture	6.0	14.0	20.25	18.25	30.25

---

*These are rough estimates derived from plotting each of these configurations to scale for groups of 20 students computing the total area and dividing by 20 to yield an average per student space allocation.

where F_L and F_W are the length and width of a furniture item (in feet) respectively (Table 3-7a); A_F and A_S represent front and side aisle space (in feet), respectively (Table 3-7b).

For radial and circular configurations the computation is

$$SQ.\ FT. = F_L \cdot F_W + C$$

with F_L and F_W as before and C = the circulation space estimate for a configuration given in Table 3-9b.

Given the square feet per student designation, the simulation proceeds to select an appropriate area in three stages. First, for a particular activity, a furniture item is chosen. This choice is based on estimated frequency distributions of furniture types for each of six activities; art, language arts, math, music, science, and other (Table 3- 8). (The distributions are estimated because furniture was not consistently recorded on the observation sheet. Then, a configuration type is selected as in the procedure for determining space needs (Section 3.3.1.1). Finally, given configuration and furniture, Table 3- 9 is entered and the square feet per student designation is extracted.

3.3.2 Determining the Nature of the Activity

A second characteristic of an activity which could

TABLE 3-9

ESTIMATED PERCENTAGE DISTRIBUTIONS OF FURNITURE USED IN INSTRUCTIONAL ACTIVITIES

Furniture Type \ Activity	ART	LARTS	MATH	MUSIC	SCIENCE	OTHER
Desk	40.0	40.0	50.0	5.0	30.0	40.0
Table	40.0	25.0	45.0	2.0	60.0	30.0
Chair	0.0	20.0	0.0	80.0	5.0	10.0
Nofurn	20.0	15.0	5.0	13.0	0	20.0

be used as a constraint in the selection of an appropriate space in which to conduct the activity was defined to be the nature of the activity. This characteristic was a composite of two observed features of an activity, namely, whether or not the students were working individually and whether or not they were under some supervision. The major effect these features would have on the choice of a space is that for a group of students, under supervision, working as a group, the space should be convex to allow a line of sight between any two students.

Since there were only four cases, a joint frequency table was generated for the two features so that they could both be obtained in one operation. Table 3-10 shows the observed frequencies and their associated percentages.

To obtain the nature of an activity, a number between 1 and 4 is generated according to the frequencies in the table and the associated pair denoting individual work and supervision is assigned as a characteristic of the activity.

3.3.3 Determining the Distraction Factor

The distraction factor (DF) was a number from 1 to 4 with which observers attempted to categorize the potential an activity had for distrubing an adjacent activity assuming there were no intervening walls. It was based on the

TABLE 3-10

JOINT FREQUENCY PERCENTAGES OF GROUP TYPE AND PRESENCE OF SUPERVISORY PERSONNEL

Group Type	Supervisory Personnel	Percent of Observed Frequency
Group	Yes	59.39
Group	No	13.45
Independent	Yes	16.24
Independent	No	10.92

TABLE 3-11

FREQUENCY AND PERCENTAGE OF OBSERVED DISTRACTION FACTOR BY ACTIVITY

Distraction factor		Activity				
		ART	LARTS	MATH	SCI	OTHER
1	Count	28	279	62	53	98
	% Col	52.83	61.97	44.93	54.64	52.13
2	Count	14	125	44	30	48
	% Col	26.42	27.96	31.88	30.93	25.53
3	Count	11	40	27	12	41
	% Col	20.75	8.95	19.57	12.37	21.81
4	Count	0	5	5	2	1
	% Col	0.0	1.12	3.62	2.06	.53
	Total Count	53	447	138	97	188

observer's judgment of the amount of noise and physical action involved in the observed activity. In determining the placement of an activity into a space, the assumption would be that high distraction activities should be located away from other, ongoing activities.

Assuming that the distraction potential of an activity was independent of school program, and that the DF was recorded consistently, a frequency table was generated for instructional activities using data from all three schools observed (Table 3-11). For the class of activities observed, the results showed an expected concentration of low distraction potential values.

A distraction factor is assigned to an activity according to the observed frequency distribution.

3.3.4 Determining the Resource Requirements for an Activity

The final characterization of an activity consisted of a specification of equipment required for efficient functioning of the activity. The model was to be based upon the observed use of equipment; however, as stated earlier, what information was recorded was of little use. Nevertheless, to assign an activity to a space, it was felt that the resources of the space should, if possible, satisfy the requirements of the activity. Therefore, frequency distributions of equipment were estimated for six activity types--Art, Language Arts, Math, Music, Science, and Other. For each activity, the thirteen equipment categories and their probabilities are shown in Table 3-12.

Again, the method for choosing an equipment item for an activity is to pick an item according to the frequency distribution of items for that activity in the table.

3.3.5 Discussion

Methods for modeling four characteristics of an elementary school activity have been presented. Two of them, the nature of an activity and the distraction potential were derived from data collected during the observation phase of this research. A third, resource or equipment requirements was estimated. The general paradigm was to generate tables depicting the frequency distributions for a set of factors and then to select factors with a probability reflecting the derived frequency percentage.

Two models were proposed for the fourth characteristic, square feet per student per activity. This was to allow a designer to choose whether a simulation should be conducted under optimal conditions or whether it should reflect observed space use. The answer depends on the use to which the simulation will be put. The optimal figures could be used in determining basic space needs and thus in establishing lower bounds on size in the design of classrooms or

TABLE 3-12

ARBITRARY PERCENTAGE DISTRIBUTIONS OF EQUIPMENT USED IN INSTRUCTIONAL ACTIVITIES

	Activity					
	ART	LARTS	MATH	MUSIC	SCIENCE	OTHER
BLACKBOARD (BB)	05.00	50.00	70.00	05.00	65.00	10.0
PORTABLE BLACKBOARD (BP)	05.00	15.00	10.00	05.00	05.00	10.0
RECORD PLAYER (RP)	0.0	05.00	0.0	20.00	0.0	05.0
TAPE RECORDER (TR)	0.0	05.00	0.0	10.0	0.0	10.0
MOVIE SCREEN (MS)	0.0	05.00	0.0	0.0	08.0	0.0
MOVIE PROJECTOR (MP)	02.00	0.0	0.0	0.0	06.0	0.0
SLIDE PROJECTOR (SP)	02.00	0.0	0.0	0.0	0.0	0.0
FILMSTRIP PROJECTOR (FP)	0.00	0.0	0.0	0.0	11.0	15.0
TELEVISION (TV)	0.00	05.0	15.0	05.0	0.0	05.0
RADIO (RA)	0.00	05.0	0.0	05.0	0.0	05.0
EASEL (EA)	20.0	0.0	0.0	05.0	0.0	0.0
SINK (SI)	20.0	0.0	0.0	05.0	05.0	0.0
PIANO (PI)	0.0	0.0	0.0	45.0	0.0	0.0

open-style pods. It must be remembered, however that the actual space utilized and the space necessary to carry on an activity may be substantially different. As was mentioned previously, in a spatial environment such as that of School A an activity may be perceived as occupying 7200 feet of space even though only 7 or 8 students are involved. Since the simulation program will generate such space needs, it is recommended that optimal space figures be used for most applications.

CHAPTER 4

Simulation Technique

4.1 Introduction

In this and the following two chapters the techniques used to simulate educational activities on a proposed floorplan are described. The current chapter presents an overall view of the system, then describes significant aspects of the flow of information from a functional perspective.

4.1.1 System Design

The entire simulation system is portrayed in Figure 4-1. The data collection and analysis phases have been described earlier. In addition to the activity descriptors, a floorplan, a schedule of activities, and a set of simulation parameters must be provided to the simulator which, as it proceeds, produces data pertaining to the utilization of space.

The simulator itself is described from a functional perspective in Section 4.3. The description details the flow of data through the system and provides the overall logic incorporated into the simulation. Succeeding sections describe in detail the parameters to the system, other inputs (the school floorplan, and the block schedule), control structures, and the outputs. Algorithms for generating characteristics of activities and detailed schedules are also presented.

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OVERALL SYSTEM DESIGN

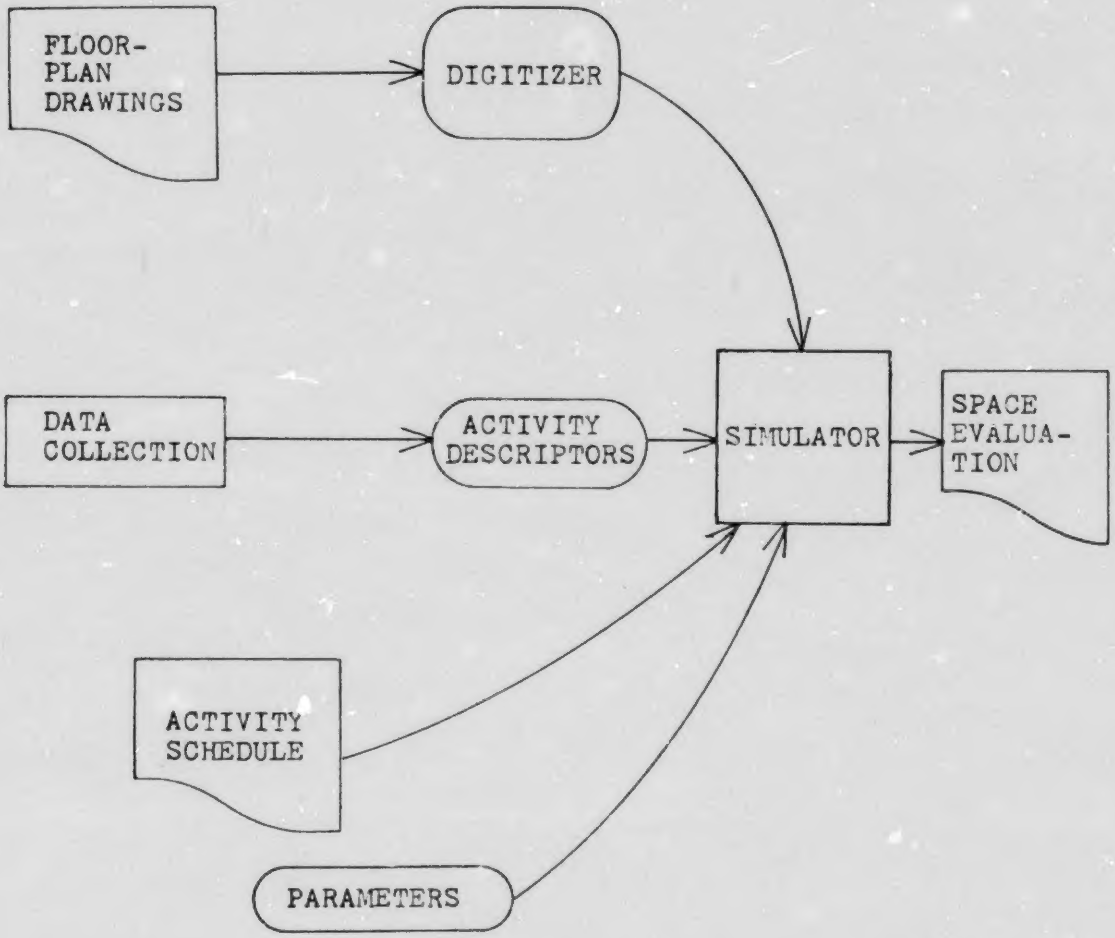
FLOOR-PLAN DRAWINGS
DIGITIZER
DATA COLLECTION
ACTIVITY DESCRIPTORS
SIMULATOR
SPACE EVALUATION
ACTIVITY SCHEDULE
PARAMETERS

Figure 4-1

4.2 Some Preliminaries

Preliminary concepts and processes basic to any simulation and their employment in this one are presented in this section. For more detailed information the reader is referred to bibliographic reference of the following discussion is drawn.

A computer simulation is a technique for performing and analyzing experiments on a model of a real system. It can be a costly way to do experiments and often requires a lengthy period of time to develop, but it provides the experimenter with a flexible method with which to test alternatives, combine many factors, and get the benefit of rapid feedback. In the specific area of school architecture, the ability to test the functionality of a design before building the facility could, theoretically, provide a great cost benefit.

A system can be discrete or continuous. A discrete system is one in which all changes in the state of the system are assumed to happen at discrete moments in time; a continuous system is one whose components are under continuous change [18]. It is the model of a system which determines whether the system which is to be simulated may be stochastic or deterministic. If it is deterministic, then for a particular state a given input to the system will result in a particular known output. For a stochastic system in a certain state, a given input can result in one of a range of outputs whose distribution may be known, but the exact response to the input would be otherwise unpredictable.

A digital computer is an example of a deterministic system. From the description of the current state of the system and specification of the next input, the succeeding state may be derived. Games of chance such as poker or craps, are stochastic. Nothing about the previous throw of a pair of dice, for example, provides a clue as to the results of the next throw; the range of values and their distribution, however, is well known.

The system modeled in this thesis, a complex of educational activities, is stochastic and discrete. A stochastic model of the system was presented in the last chapter vis-a-vis distributions based on observations of elementary school activities. The system is discrete because changes in the system can be completely specified at those moments in time when there is a change in the ongoing activities according to a generated schedule.

Two possible approaches can be employed in the implementation of a simulation with respect to the chronology of the set of events taking place: a critical event approach or a time-slice approach. The critical event method describes a sequence of events as a causal chain and reports the state of the system at each new set of events between the starting and ending event. Using the time-slice method, the state of the system is sampled at specific, usually regular, intervals of time, and is modified to reflect the effects of new or changing activities in the system taking place over the preceding time interval[22].

The simulation described in this thesis utilizes a time-slice approach, stepping through a schedule of activities at regular intervals of time and updating the state of the system based on the current set of activities in process.

One final aspect of simulations which is of importance is the simulation parameter. A simulation parameter is a variable which describes some characteristic of the environment of a system and which can be specified at the outset of a simulation run. For example, the simulation of the performance of a time-sharing operating system would likely have as a parameter, the size of the high-speed memory available to the system.

A simulation can have several parameters. The ability to change the values of parameters and see their effects provides the user with a flexible, informative way of assessing the performance of the simulated system,

4.3 Functional Description

The simulation system described in this section consists of a controlling routine and a set of subroutines organized as shown in Figure 4-2. The controlling routine reads the input parameters and accesses the appropriate set of activity descriptors for modelling the specified school program. A proposed floorplan in tree-structured form is then input along with a list of names for spaces and subspaces on the plan (the representation of the floorplan is discussed in detail in Chapter 5). For each space and subspace, the area is computed; then the entire list of spaces is sorted into ascending order on area. The program which computes the area of spaces (see Appendix C) can also set an indicator showing whether a space has any concave vertices.

For each classroom or unit (depending on school organization) a "block" schedule is input. A block schedule is one in which a school day is divided into four or five blocks of time, up to two hours each, during which a major subject area is pursued. Concurrent, specialized activities such as physical education or workshop, which would take place in other designated spaces can also be specified on the block schedule, an example of which is shown in Table 2-1.

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FUNCTIONAL FLOWCHART OF SIMULATION SYSTEM

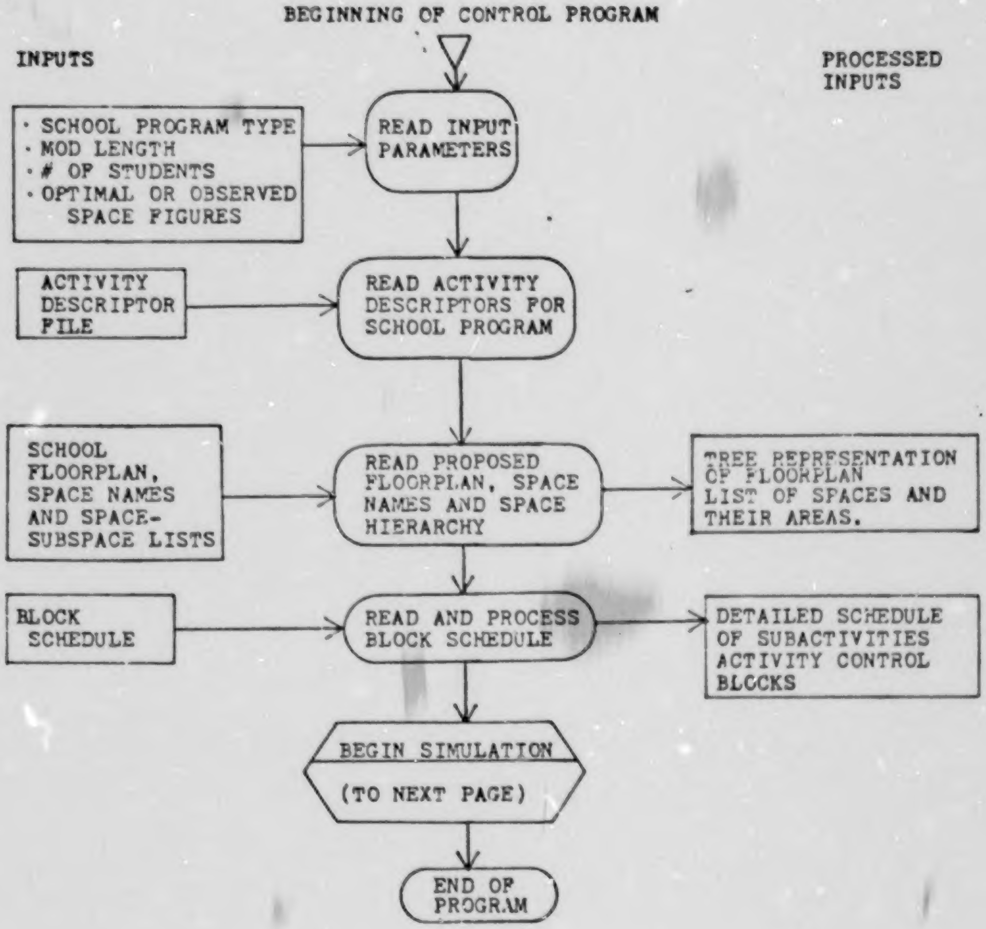
BEGINNING OF CONTROL PROGRAM
INPUTS
PROCESSED INPUTS
· SCHOOL PROGRAM TYPE
· MOD LENGTH
· # OF STUDENTS
· OPTIMAL OR OBSERVED SPACE FIGURES
READ INPUT PARAMETERS
ACTIVITY DESCRIPTOR FILE
READ ACTIVITY DESCRIPTORS FOR SCHOOL PROGRAM
SCHOOL FLOORPLAN, SPACE NAMES AND SPACE-SUBSPACE LISTS
READ PROPOSED FLOORPLAN, SPACE NAMES AND SPACE HIERARCHY
TREE REPRESENTATION OF FLOORPLAN
LIST OF SPACES AND THEIR AREAS.
BLOCK SCHEDULE
READ AND PROCESS BLOCK SCHEDULE
DETAILED SCHEDULE OF SUBACTIVITIES
ACTIVITY CONTROL BLOCKS
BEGIN SIMULATION
(TO NEXT PAGE)
END OF PROGRAM

Figure 4-2

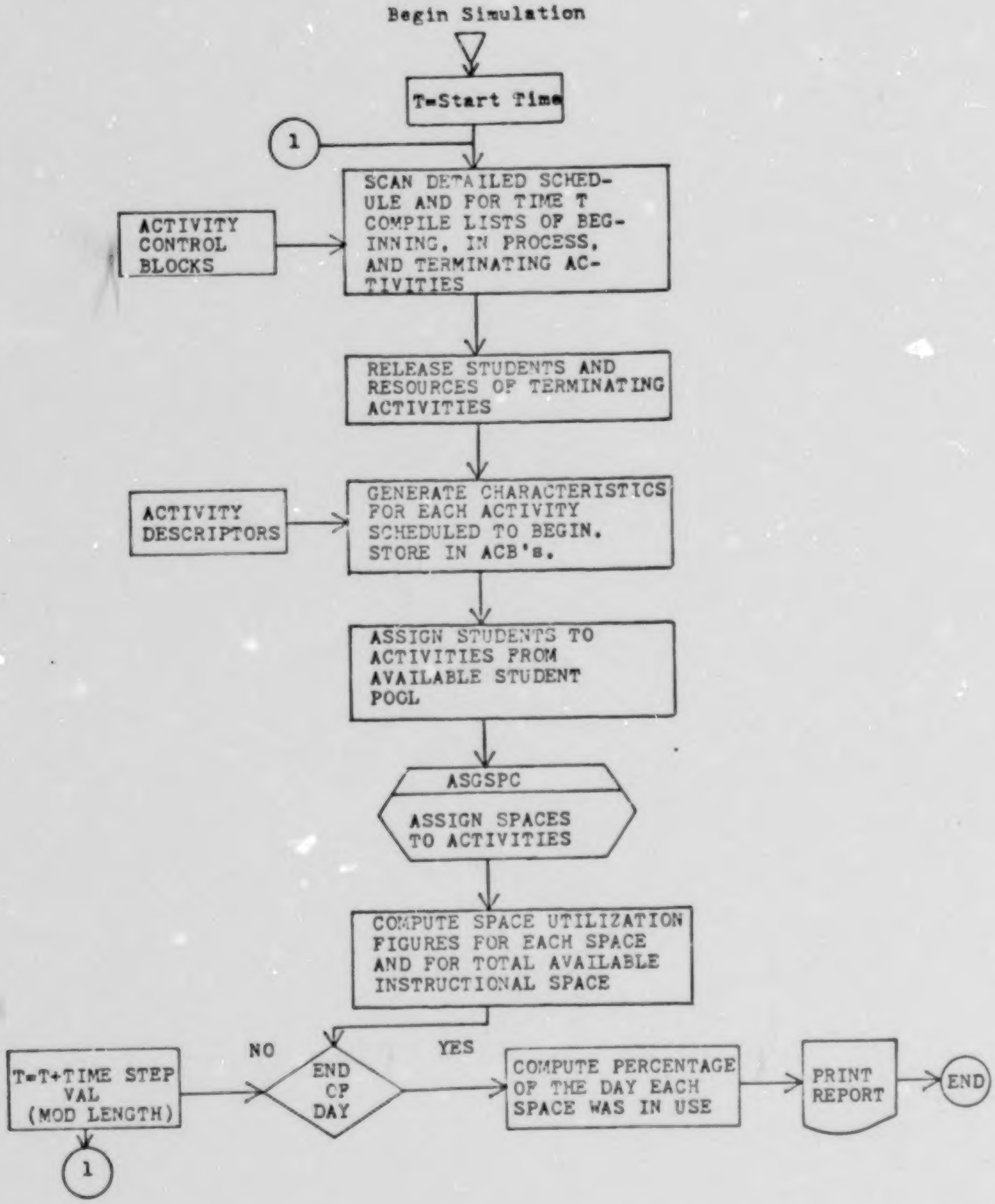
Begin Simulation
T=Start Time
1
SCAN DETAILED SCHEDULE AND FOR TIME T COMPILE LISTS OF BEGINNING, IN PROCESS, AND TERMINATING ACTIVITIES
ACTIVITY CONTROL BLOCKS
RELEASE STUDENTS AND RESOURCES OF TERMINATING ACTIVITIES
ACTIVITY DESCRIPTORS
GENERATE CHARACTERISTICS FOR EACH ACTIVITY SCHEDULED TO BEGIN. STORE IN ACB's.
ASSIGN STUDENTS TO ACTIVITIES FROM AVAILABLE STUDENT POOL
ASGSPC
ASSIGN SPACES TO ACTIVITIES
COMPUTE SPACE UTILIZATION FIGURES FOR EACH SPACE AND FOR TOTAL AVAILABLE INSTRUCTIONAL SPACE
NO
YES
END OF DAY
T=T+TIME STEP VAL (MOD LENGTH)
1
COMPUTE PERCENTAGE OF THE DAY EACH SPACE WAS IN USE
PRINT REPORT
END

Figure 4-2

From the block schedule, a detailed schedule of activities is generated. The detailed schedule subdivides the blocks of time allocated in the block schedule into a set of subactivities in such a way as to reflect grouping practices employed by schools using differing methodologies and incorporates a model of activity duration as described in the previous chapter.

Each activity in the detailed schedule is assigned an Activity Control Block (ACB) which is one of the central logical structures accessed and utilized by the simulation program. A detailed description of the ACB is provided in Section 4.6. For now, it suffices to know that the scheduled starting and ending times of an activity and its group size are among the data stored in each ACB when it is initialized.

Once all of the initialization processes have been completed, the controlling program calls a subsystem of programs which perform the actual simulation (see Figure 4-1). The simulation proceeds using a time-slice approach whereby time is initialized at the earliest time on the input schedule and incremented by regular amounts until the end of the schedule is reached. At each interval of time the detailed schedule is scanned for all activities which are beginning, in process, or terminating, and compiles these into separate lists.

The terminating activities are processed first. Their resources and students are returned to their respective eligibility pools and the spaces which they occupied are flagged as available. Next, the activities scheduled to begin are processed. Specific students are chosen from the pool of available students and assigned to each activity according to the previously computed group size in the ACB.

In assigning students to activities, the assumption is that the selection of any given student for an activity is a random process. Each activity scheduled to begin has been assigned a group size by the detailed schedule generator. The available student pool initially consists of all the students in the school and is subdivided to reflect the assignment of students to units, pods, or homerooms as the case may be. At any subsequent period, the pool consists of the union of any previously unassigned students and those students compiled from the list of activities terminating at that period. Each student is also assigned a number from 1 to n where n is the total enrollment in the school. Students assigned to a particular unit are represented by a set of contiguous numbers. Thus to assign a student to a group in an activity, a uniformly distributed random number is generated within the range of student numbers of the appropriate unit and that student is assigned to the activity.

Each activity is then assigned characteristics reflecting the information contained in the file of activity descriptors. These characteristics include: 1) space per student needs, 2) the type of furniture to be used, 3) equipment needs, 4) a distraction factor, and 5) a group type indicator specifying whether a group is working as a group or as individuals and whether the group is supervised or unsupervised.

When the activities have been completely characterized, the program assigns activities to spaces in such a way as to find a reasonable fit between the activities and the spaces which are available for them. At this time the lists of new activities and the activities in progress are scanned and space utilization figures are compiled. At the end of the simulated day, all the space utilization figures plus other compiled information is output for analysis; the school designer can then modify the design, if appropriate, and restart the simulation.

The assignment of activities to spaces is a particular instance of the linear programming "assignment problem". A formalization of this problem and the method employed in the simulation to deal with it are presented in Chapter 6. The succeeding sections of this chapter provide the details for the functional specifications presented thus far. First, the parameters and input files are described, followed by a description of the algorithm.

4.4 Parameters to the Simulation

There are four basic parameters which must be defined for the simulation program. These are SCHOOLTYPE, ENROLLMENT, MODLENGTH, and SPACECALC. SCHOOLTYPE designates the school program which is to be simulated and directs the program to use a data base consisting of scheduling information and activity descriptors derived from the observation of similar programs. ENROLLMENT specifies the number of students in each pod, unit, or independently organized room to be assigned to an initial pool of availability for use by the simulation. MODLENGTH is the unit of time the simulation program will use to define its time-slice interval. By specifying a larger unit of time for MODLENGTH (e.g., 15 or 20 minutes), the scheduler can be made to generate schedules resembling modular schedules; whereas the selection of a smaller interval such as 5 minutes will result in more variable schedules. Finally, the SPACECALC parameter declares whether the program will use optimal or observed space per student figures in its computation of space necessary for activities.

4.5 Other Inputs to the Simulation

4.5.1 School Floorplan and Space List

In addition to the simulation parameters, the simulation takes as input a school floorplan which defines the environment for simulated activities. Ideally, this process would be totally interactive, however, as a prototypic system, such a capability has not been implemented. Currently, a floorplan--specifically the instructional spaces on the floorplan--are defined by a set of x, y coordinates specifying a set of vertices of the space, and punched onto cards. A mechanical digitizer owned by the Department of Cartography at the University of Wisconsin and connected to a keypunch machine it utilized to prepare the punched card input for the computer. Non-circular spaces are defined by a set of n points (x_i, y_i), $(i=1,2,\ldots,n)$ which are recorded in counterclockwise order. Circular spaces are defined by a center point and a point on the circumference. As many points as are necessary may be used to define a space completely, and there is no restriction on the shape of a space. Preceding each card or set of cards containing the x, y coordinates of a space is a card with a name which is to be assigned to the space, and the number of coordinate points used to define the space. To complete the description of the floorplan, a list of the spaces must be prepared which defines the space-subspace relationship between the spaces on the floorplan. Accompanying each of the lowest level subspaces--those spaces which are not further broken down--is a list of furniture and equipment in the subspace.

4.5.2 Schedule

A schedule such as was described in Section 4.3 and depicted in Table 2-1 is read for each unit, pod, or classroom in the school which is to be simulated. The schedule provides a guide to the subactivity shcedule generator which is explained in Section 4.

4.6 The Activity Control Block

Each activity generated by the scheduler is assigned an Activity Control Block (ACB). The contents of an ACB reflect the current status of an activity as well as some ancillary information. One of the two major logical data structures in the simulation system, the ACB is central to the decision making processes involved in simulating the assignment of activities to available spaces. The ACB is shown in its entirety with its relationship to some subsidiary data structures in Figure 4-3. Following is a detailed explanation of each entry in the ACB.

ENTRY	
Activity Number	An index to the entry in a table of activity names which designates the activity this ACB represents
Start Time	The scheduled starting time for this activity
End Time	The scheduled time of completion for this activity
Status	Tells whether or not an activity has been activated and given a location: 1 = not assigned 2 = in process 3 = assigned
End of Schedule Indicator	A "1" indicates end of schedule
Area Required	Total area in square feet required for this activity

Student Pointer	A pointer to a list which is a string of binary digits. If the n^{th} digit is a "1", then student n has been assigned to this activity
Number Assigned	The number of students assigned to the activity
Location	Name of the space to which activity is assigned
Configuration	Configuration of students' in the space
Nature	Nature of the activity--supervised group, unsupervised group, supervised independent work, unsupervised independent work
Distraction Factor	The numeric designation of the distraction factor assigned to this activity
Space Pointer	A pointer to a list of potential spaces, to one of which this activity may be assigned. Each entry in the list contains the name of the space and a score which reflects the degree to which that space can satisfy the requirements of the activity
Furniture and Equipment Vector	A 36 place vector, each position of which represents an item of furniture or equipment. The value of each position is a 0 or 1. A 1 indicates that the activity requires the item represented by the position in which the 1 appears.
Furniture and	A pointer to a table which lists the quantities of each of the furniture and equipment items denoted by the furniture and equipment vector.
Priority	The priority of an activity. It is used by the assignment algorithm to determine an ordering in which activities will be processed for assignment. (See Chapter 6.)

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THE ACTIVITY CONTROL BLOCK

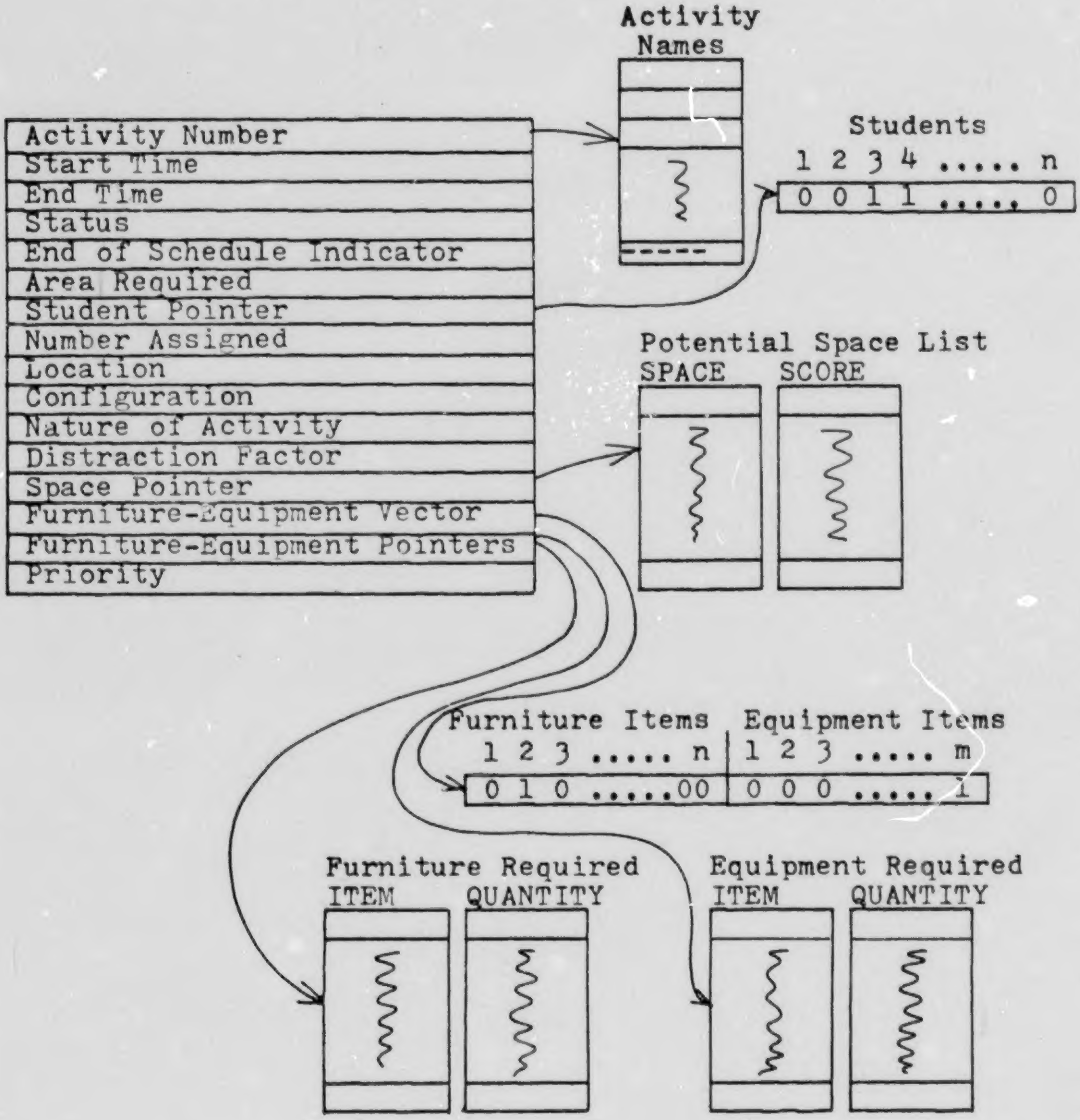
Activity Names
Students
1 2 3 4 ..... n
0 0 1 1 0
Activity Number
Start Time
End Time
Status
End of Schedule Indicator
Area Required
Student Pointer
Number Assigned
Location
Configuration
Nature of Activity
Distraction Factor
Space Pointer
Furniture-Equipment Vector
Furniture-Equipment Pointers
Priority
Potential Space List
SPACE
SCORE
Furniture Items
1 2 3 ..... n
0 1 0 00
Equipment Items
1 2 3 ..... m
0 0 0 1
Furniture Required
ITEM
QUANTITY
Equipment Required
ITEM
QUANTITY

Figure 4-3

4.7 Generating Characteristics of Activities from Frequency Distributions

From the analysis of observation data described in the previous chapter a set of tables was prepared which represent the distributions of the values of activity characteristics. The values of characteristics were categorized as one of two types, range values and explicit values. Group size is an example of a characteristic which was defined as a set of ranges, namely, 1-6, 7-16, 17-35, and 35+. Distraction factor is a characteristic which is divided into distinct values, (1, 2, 3, and 4). The frequency distributions, therefore, reflect the percentage of times a category of a characteristic was observed, whether it was a range or an explicit value.

For use in the simulation program, each of the frequency distributions derived in Chapter 3 was transformed into a cumulative frequency distribution. Accompanying each distribution is a list of ranges or values the characteristic will take at each frequency.

For each value, N, to be generated for a characteristic, the following algorithm is used.

Algorithm SIMFRQ

Given a table of n ranges or explicit values CAT, defining a characteristic for an activity and a cumulative frequency distribution FREQ defined at each entry of CAT:

1) Generate a random number K between 0.0 and 1.0. Set K = 100*K.

2) Initialize i to 1.

3) While K > FREQ[i] set i=i+1. (If i > n, set N← -1 and return.)

4) If CAT is a set of explicit values, set N← CAT[i] and return.

otherwise

5) Set N← a random number between CAT_L and CAT_U, the lower and upper limits of the range of the values for the category and return.

In Step 1 a standard random number generator is used to produce K, a uniformly distributed random number between 0 and 1 which, when multiplied by 100 can be compared against the percentage stored in FREQ--a table containing the cumulative frequency percentage at each category of the characteristic to be simulated. Step 3 performs the comparison until K is less than the i^{th} value in FREQ or the end of the table has been found. At this point, the following holds:

Assume FREQ[j], $1< j < n+1$ is the entry in FREQ at which the comparison in Step 3 stopped. Then p_j=FREQ[j] - FREQ[j-1] is the percentage of frequency of category CAT[j] of the characteristic being simulated by virtue of the fact that the entries in FREQ represent the cumulative frequencies for the characteristic. Since 100*K is a uniformly distributed random number and $0 \leq \text{FREQ}[i] \leq 100$ for $i=1,n$, the probability that K will fall between FREQ[i] and FREQ[i-1] is $p_i = \text{FREQ}[i] - \text{FREQ}[i-1]$. CAT[j] will therefore be chosen with probability p_j. Thus the algorithm chooses categories of characteristics at the same relative frequency which they were observed.

At Step 4 the algorithm tests whether the category represents a range or an explicit value. In the latter case, the algorithm terminates with the value of the chosen category. For the former case, Step 5 is invoked to generate a uniformly distributed random number K such that $\text{CAT}_L \leq K \leq \text{CAT}_U$ which is returned as the value of the algorithm.

Finally, in the event that in Step 3 $i>n$, the algorithm terminates with an indication that no value was assigned. This is possible, for example, where an activity uses equipment 45 percent of the time, hence, the highest value in FREQ is 45.0; any number K greater than 45.0 indicates no equipment is to be assigned as a requirement for the activity.

4.8 Generating Schedules

Preliminary to the main process of the simulation, the block schedule which has been input is processed to yield a detailed schedule of subactivities which will take place during each major block of time. It is the schedule of subactivities, each with its own ACB, which is processed during the simulation phase and about which pertinent data is collected and analyzed. The generation of this schedule includes the assignment of a group size and a duration to each subactivity based on the data collected for the school program to be simulated.

The major assumption underlying the generation of detailed schedules is that the schedule of activities for a given elementary school program is a stochastic process which can be modeled independent of the reasons for which a given activity might be scheduled by a teacher or team of teachers at a given time and with a given group of students. That is, it is possible to predict the occurrence and certain aspects of an activity in the same way as it is possible to predict the liklihood of an automobile accident--where it might occur, and under what conditions--by having a statistical model of the occurrences of such events.

4.8.1 An Algorithm to Generate Schedules

Under the stated assumption a reasonably simple algorithm has been derived for generating schedules of subactivities. Inputs to the algorithm are:

1) MODL--a parameter to the simulation which states the value of the time-step interval
2) NS--the number of students
3) GFREQ--for the school program to be simulated, a cumulative frequency distribution of group size for each activity to be simulated
4) DFREQ--a cumulative frequency distribution of activity duration
5) ACTBLK--a block schedule
6) STTIME--the starting time for the schedule

The result of executing the schedule generating algorithm is a set of ACB's each of which is a 19 word record stored contiguously into the array ACTSCH. Each ACB will contain the activity number, its start and end time, a section number (to differentiate subactivities from one another) and a group size.

Algorithm SCHGEN--the schedule generator

1) (Initialize) Set NSAV ← NS, T ← STTIME, NDX 1,

1a) (outer loop) while NSAV > 0 do Steps 2-6 (Generate subactivities until number of students available is 0.)

2) (Initialize inner loop) Set K ← index of next available ACB in ACTSCH, SECNO next available section number for this activity.

3) (Check for end of block schedule) IF ACTBLK[NDX]=⋀ terminate. (⋀ is an end of data indicator.)

4) (Get a group) CALL SIMFRQ with GFREQ, the frequency distribution of group size for activity of ACTBLK[NDX]. Set ACTSCH[K+MA]← minimum (GS,NSAV). (ACTSCH[K+MA] is the maximum assignable number of students for this subactivity. GS is the group size generated by SIMFRQ. NSAV is the number of students left in the available student pool. Whichever of GS or NSAV is least is assigned to the ACB. Set NSAV← NSAV-ACTSCK[K+MA]. (Update NSAV to show current number of students available.)

5) (Get a duration) CALL SIMFRQ with DFREQ, the frequency distribution for activity durations. Set TIMLEN ← result of SIMFRQ.

6) (Adjust duration and enter into ACB) Let TDIFF = difference in minutes between proposed ending time of subactivity (based on duration computed in Step 5) and ending time of the block. If 0<TDIFF<MODL or TDIFF 0, set TIMLEN=TIMLEN+DIFF. (If either of the two above conditions hold, have the activity terminate at the end of the block.) Otherwise:
Set TROUND←[((TIMLEN/MODL]*MODL)*2/MODL]
(TROUND now equals 0 or 1 depending on whether the duration TIMLEN was longer than MODL/2 minutes past the last integral mod of time.)
Then set TIMLEN←([TIMLEN/MODL]+TROUND)*MODL. (This adjusts TIMLEN to the nearest integral MOD of time.) Finally, if TIMLEN=0 at this point, set TIMLEN←MODL so activity cannot take zero time. After adjustment, store beginning time, end time, and section number into ACB.

7) (Step time to next integral mod) T←T+MODL. If T > end time of block then: set SECNO←0; NDX← next block in ACTBLK. Otherwise proceed to Step 8.

8) (Collect students released from subactivities ending at time T) NSAV←NSAV+sum of students in terminating subactivities. Return to Step 2.

This algorithm generates activities or subactivities at a given time T until there are no more students available. It then steps to the next unit of time within the current block, collects the students out of terminating subactivities and creates new subactivities from this pool of students. Each time an activity is generated, its duration is also calculated. Both group sizes and durations are based on the models derived in Chapter 3.

The inputs to the algorithm are for the mostpart self explanatory, however, the MODL parameter deserves some additional mention. Varying the MODL parameter serves two purposes. It determines the number of times the simulation collects data about the status of space use in a simulated school, and it also has an effect on the regularity of a schedule of subactivities. What is meant by regularity, is that there will be a greater tendency for activities to all start and end at the same time when MODL is large than when it is small. The reason for this is that when the algorithm generates a duration for an activity, it rounds to the nearest integral "mod" time boundary. Thus, for larger values of MODL, schedules look more like those which would occur in a modular scheduling system, whereas for small values, a more flexible, variable schedule is generated.

4.9 Outputs from the Simulation

Outputs from the simulation consist primarily of space utilization data. Of course, how spaces are used in the simulation, depends on the method by which a given space is assigned to a particular scheduled activity. Details of this procedure are given in Chapter 6.

Preliminary to the space utilization figures, the following information is presented to define for the user the conditions of the simulation:

- The parameters for the simulation
- A list of spaces in the proposed floorplan design and their areas
- The block schedule
- The schedule of subactivities generated from the block schedule

The parameters are simply those which the user provided as is the block schedule. The areas of the spaces on the input floorplan are computed and presented for the designer's convenience. The schedule of subactivities will vary according to the simulation parameters and is a major input to the active simulation phase of the program.

Specific space utilization data is collected and/or computed during each time step, and at the end of each simulated day. Following is a summary of outputs:

1. The activity name
2. The activity start and end times
3. Number of students assigned to the activity. (An optional listing of students by student number is also available.)
4. Furniture and equipment requirements
5. The nature, configuration, and distraction factor assigned to the activity by the simulation program
6. Area of the space required by the activity
7. Name of the space assigned to the activity
8. Furniture and equipment inventories of the space
9. Area of the space assigned
10. Percentage of the space utilized by the activity

Following the list of scheduled activities the percentage of space in use of the total available instructional space is computed for each time step. At the end of the day, the percentage of use of each space in terms of the total amount of time it was available is output.

The three computations of percentage of space utilized are made according to the following formulas:

1. Ratio of space required to space utilized by an activity--$P_A(S)$,

   Let A_R = area of space required by the activity,

   A_S = area of space assigned to the activity.

   Then $P_A(S) = A_R/A_S$.

2. Percentage of total instructional space in use at each time step--$P_T(S)$

Let n = number of activities in progress at a given time step

A_{S_i} = Area of space assigned to the i^{th} $(1 \leq i \leq n)$ activity in progress during this time period.

A_T = Total area of instructional space available.

Then $P_T(S) = \sum_{i=1}^{n} A_{S_i}/A_T$.

3. Percentage of time a space is in use of total amount* of time available--$P_{use}(S)$

Let M_T = total number of instructional mods in the daily schedule

M_j = number of instructional mods space j was in use during the day

Then $P_{USE}(S) = M_T/M_j$.

With the outputs provided, a school designer can evaluate the way the spaces he has designed will likely be used. Using his own values as to what those figures should be, he can adjust, if he likes, the floorplan, the schedule (by varying the MODL parameter and/or the enrollment parameter), school program and check optimal or observed space needs to see their effects before deciding upon a final design. Some examples of the use and output of the program are given in Chapter 7.

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*The amount of time is given in units of value MODL, the time interval parameter. This is because if a space is in use, it is assigned for an integral number of mods.

4.10 Summary

A functional description of a system which simulates elementary school activities and analyzes their impact on instructional space has been presented. The major logical control structure, the Activity Control Block, was described, and algorithms for generating schedules and simulating characteristics of activities were given. Finally, a list of outputs from the system and their computations, when appropriate, were shown.

In the following chapter, details of a data structure to represent school floorplans are presented. Chapter 6 describes the algorithm which makes assignments of scheduled activities to spaces, and some examples of the use of the program are given in Chapter 7.

CHAPTER 5

An Approach to the Representation of Floorplan Problems

5.1 Introduction

This chapter gives a detailed description of a spatial representation for school floorplans. In the previous chapter, the activity control block was presented--a structure which simultaneously representa the state of an activity and its scheduled occurrence. In the simulation, once a schedule of activities has been generated and their characteristics computed, a process of finding appropriate space for activities is initiated. This process, explained in detail in Chapter 6, attempts to satisfy a set of requirements and constraints posed by the set of activities. The ability of the program to assign spaces which comply with the requirements and constraints of activities is in part dependent on the accessibility of that information about spaces which pertain to these criteria.

Additional consideration must be given to the fact that in a constantly changing environment such as an elementary school, spaces are assigned and released quite often. Simulating this kind of situation requires accurate accounting of what spaces are available and at what times.

Furthermore, because of the observed tendency of teachers to subdivide rooms and spaces to accommodate groups, the assignment of a particular space may make its subspaces and/or the hierarchy of spaces containing that space unavailable. This, too, must be reflected in the spatial representation.

In light of the given reasons and others which will be described later in this chapter, a tree structured representation of floorplans has been developed. One particularly convenient aspect of this representation is that it accurately reflects the space-subspace relationship cited earlier.

5.2 Criteria for Floorplan Representation

5.2.1 General Requirements

The purpose of a representation for floorplans is not simply to represent the shape of a region and spaces within it. In fact the representation provides access, either directly or indirectly, to various properties of a space which are essential to solution of a design problem. Problems which require such representations either attempt to design floorplans or to enter objects into an existing floorplan all under a set of well defined constraints.

Some general statements can be made about the requirements of a spatial representation. In particular there are five primary properties of space which are of interest and which should be accessible from the representation:

1. Dimensions
2. Adjacencies
3. Location
4. Distances
5. Orientation

Each of these properties relates to processes which attempt to resolve problems concerning relative locations of space and constraints on the size and/or orientation of spaces. For object placement, the addition of an object description and representation of requirements and constraints for such placements are necessary to the problem solving process.

The actual representation of the five properties can take many forms. Some may be derived from others, such as, for example, adjacencies from location. All may be derived from a list of coordinates for every space depicted on the floorplan. What goes into the final representation, however, is in large part attributable to the application to which the representation will be put.

5.2.2 Criteria for a Representation for School Floorplans

In this research, a major problem is a form of object placement--namely, the placement of activities into space. Conversely, the problem can be viewed as an assignment problem--the assignment of spaces to activities, the appropriateness of which is crucial to the validity of the space utilization data compiled by the simulation. A secondary problem is incurred in the housekeeping activity which must be performed to insure that the assignment and release of spaces are properly reflected in the structure.

Educational activities are the "objects" in the system being described and are considered to be shapeless or amorphous; although their need for space is, in part, derived from the configuration they will take. As described, the Activity Control Block is the representation for an activity and outlines its spatial requirements. These requirements are a) two types of resources; space and equipment, and b) constraints which include the schedule of activities competing for space, location relative to other activities, and shape considerations--in particular the requirement for a line of sight between any two points in the space constraints the shape of a space.

Four criteria for a spatial representation for school floorplans from these requirements:

1. Properties of the space--dimensions, area, and shape, must be available. (An activity may not have a shape per se, but it may have a requirement which constrains the shape of the space to which it should be assigned.)
2. Resources of the space should be available in terms of the inventories of furniture and equipment contained in the space.
3. The space-subspace relationship should be built into the structure to facilitate keeping track of the assignment and release of spaces to and from activities.
4. Proximity relationships with other spaces should be available to satisfy constraints on the location of activities to one another.

A data structure making accessible this information will supply most of the data necessary for determining the placement of activities into spaces.

5.3 Other Approaches to Floorplan Representation

Research into floorplan representation has been undertaken in two basic areas--computer-implemented-design, and in artificial intelligence applications. In computer-implemented-design, data structures for floorplans have evolved from work in the computer design of floorplan layouts and from the automated positioning of objects into a space, such as computer room planning or circuit board design. Artificial intelligence researchers have developed data structures which provide a robot with information about the shape and contents of the set of rooms in its environment.

An early and still widely used representation is a simple rectangular array such as that used by Armour and Buffa in a program which determines location patterns for physical facilities [5] and by Lee and Moore in CORELAP, a program which solves job shop layout problems by determining optimum arrangements of equipment and facilities [19].

The rectangular array is defined as an m x n matrix each element of which defines a square domain of the space or floorplan being represented. Each element can also take a value. The value of an element determines the object the element represents. Thus a "1" might represent a wall, "2", a corridor, "7" might be a machine, and so on. An example of a rectangular array and a key to its elements is shown in Figure 5-1.

RECTANGULAR ARRAY REPRESENTATION OF A FLOORPLAN

1	1	1	1	1	1	1	1	1	1	1	1
1	0	0	1	2	2	0	5	5	1	0	1
1	0	0	1	2	2	0	5	5	1	0	1
1	0	0	7	2	2	0	0	0	1	0	1
1	1	1	1	7	1	1	1	7	1	1	1
1	3	3	3	3	1	0	0	0	0	0	1
1	3	3	3	0	1	0	0	0	0	0	1
1	3	3	0	0	7	0	0	0	0	0	1
1	3	0	0	0	1	0	0	4	0	0	1
1	0	0	0	0	1	0	0	4	0	0	1
1	0	0	0	0	1	0	0	0	0	0	1
1	1	1	1	1	1	1	1	1	1	1	1

Key to elements:

0 = Empty
1 = Wall
2 = Desks
3 = Tables
4 = Partition
5 = Cabinets
7 = Doors

Figure 5-1

Although widely used, the rectangular array has several major drawbacks. Accuracy in the representation is limited to the size of the domain of an individual element. Placement of objects requires routines to find empty areas of appropriate sizes to fit the objects. Such areas must be built from sets of adjacent unoccupied domains. To fit them into an area, objects may have to be rotated before being placed. Any attempt to increase accuracy, which would require smaller domains for the elements, would increase the number of elements, and thus the time required to operate algorithms utilizing the rectangular array.

To improve accuracy without increasing storage requirements, yet still retain the explicit representation property of the rectangular array, researchers at Stanford Research Institute developed the hierarchical array for use in its robotics development [8] . A hierarchical array, instead of being restricted to a single predefined grid allows subdividion of the grid where more detail is necessary. Subdividions may take place up to three levels deep and may divide domains into a 4x4 grid as shown in Figure 5-2.

The hierarchical array is really used more for pattern recognition than for object placement. Thus, while accuracy

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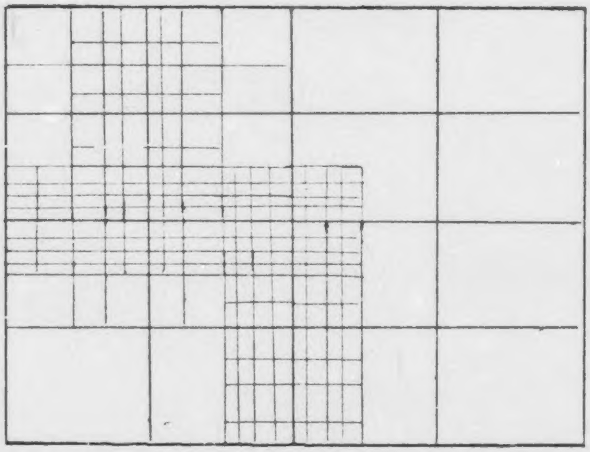
HIERARCHICAL ARRAY REPRESENTATION OF A FLOORPLAN



The dark solid line represents the walls.

Figure 5-2

VARIABLE DOMAIN ARRAY

X Y	.5	.5	.5	.5	2.0	.5	.5	3.0	3.0	.5	.5
.5	1	1	1	1	1	1	1	1	1	1	1
.5	1	0	0	0	0	0	1	0	0	0	1
.5	1	0	0	0	0	0	1	0	0	0	1
.5	1	0	0	0	0	0	1	0	0	0	1
2.0	1	0	0	0	2	2	1	0	0	0	1
.5	1	1	1	1	1	1	1	1	1	1	1
.5	1	0	0	0	0	1	0	0	0	0	1
2.0	1	0	0	0	0	1	0	3	3	0	1
2.0	1	0	0	0	0	1	0	3	3	0	1
.5	1	0	0	0	0	1	0	0	0	0	1
.5	1	1	1	1	1	1	1	1	1	1	1

Figure 5-3

may be increased without significant extra storage requirements, procedures for locating objects into a space would appear to require more complexity due to the recursive subdivision of domains in the array.

One further derivative of the rectangular array is the variable domain entry [8], a 2 or 3 dimensional matrix each of whose elements with non-zero subscripts represents a rectangular domain (Figure 5-3). The dimensions of the domain, however, are defined by the zero vectors in each dimension, thus can take values appropriate to the degree of accuracy required of the representations. Like the previous representations, the variable domain array is limited to rectangular domains and has many of the same processing requirements for locating objects into subspaces of the space being represented.

Many of the properties required in a representation of school floorplans are not explicitly represented in the rectangular array or its derivatives and would have to be computed whenever needed by the simulation. For example, there is no facility for determining the dimensions of a room without tracing around the code for a wall and building a list of the domains representing the wall. Similarly the space-subspace relationship would require additional processing to determine it. That is, the coordinates of the spaces in question would have to be derived and then analyzed to determine if the spaces were disjoint or whether one was partially or wholly contained in the other. An object entered into and removed from a rectangular array must be represented in every domain that the object covers, given its size. For educational activities it suffices to know only that a space is occupied or unoccupied; entry and removal of an activity can be signified with a flag reflecting the status of the space.

A somewhat different approach to space representation was taken by Grason in a computer implemented design of floorplans [12] . Grason defined a formal class of floorplan design problems, then designed a solution which was limited to situations described by

1. a set of rectangular rooms
2. allowable dimensions for each room
3. a set of required adjancies between rooms or between rooms and outside walls.

A programming system called GRAMPA (Graph Manipulating Package) was written which included elaborate problem solving procedures for producing a physically realizable floorplan meeting the stated criteria.

Grason utilized a dual graph representation for floorplans. He first defined a floorplan graph in a standard way (Figure 5-4a) with the edges and nodes representing wall segments and corners respectively. He then constructed the dual graph of the floorplan by placing a node inside each space (note-adjacent spaces outside the boundaries of the floorplan are considered as spaces for the purpose of node placement) and constructing edges to join the nodes of adjacent spaces. Edges were designated as dotted or dashed to represent east-west and north-south adjacencies between spaces. The direction of the edges shows orientation, and a weight associated with each edge specifies length.

Because Grason was not concerned about the use to which space would be put, his dual-graph does not have the facility for representing the properties of space necessary for making decisions on the placement of activities. No mechanism for storing inventories of the contents of a space are present. The graph shows connections between spaces but not the relationship between a space and its subspaces; nor are the coordinates of a space directly available from which to compute this information.

The dual-graph representation functions well for problems where a floorplan must be designed to satisfy dimensional and adjacency constraints and conditions are constantly changing. In its present form, however, it

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GRASON'S REPRESENTATION

GRAPH Representation
of a Floorplan

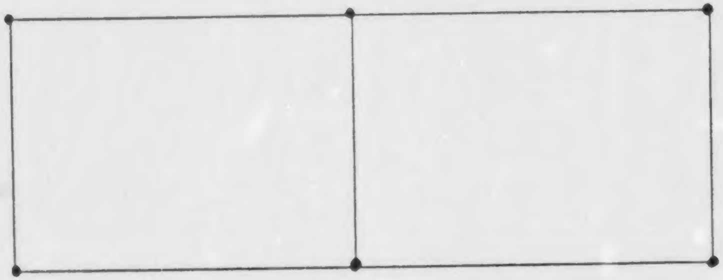

Figure 5-4a

DUAL
GRAPH
Representation
of a Floorplan

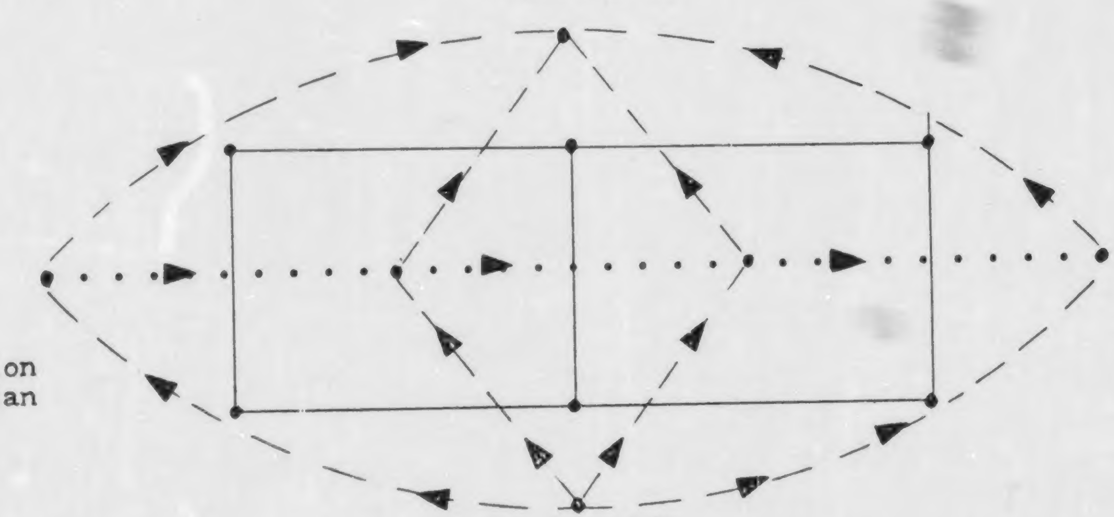

Figure 5-4b

can deal only with rectangular rooms and floorplans. Presumably, more complex shapes can be approximated by combinations of rectangular shapes.

One other representation which should be mentioned is that utilized by Charles Pfefferkorn in DPS, the Design Problem Solver [28] . DPS was written to design furniture and equipment layouts in a space. In particular problems like those involved in computer room planning where objects must be placed into a room under specific constraints with respect to distance and orientation are solved by DPS.

DPS uses a "convex polygon" representation for both spaces and the objects to be placed in them. Objects and layouts are represented by sets of convex polygons called "space blocks". The space block is a symbolic representation. Each space block is represented by a set of sides and each side by a set of two points as shown in Figure 5-5. If X is a space block then (SIDELIST X) is a list of sides in counterclockwise order. The structure is symbolic, and functions can be developed for operating upon it. Thus (NEXTTO X) can return sides of spaces adjacent to space block X . Similar functions allow the symbolic manipulation of objects in the layout.

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SPACE BLOCK REPRESENTATION

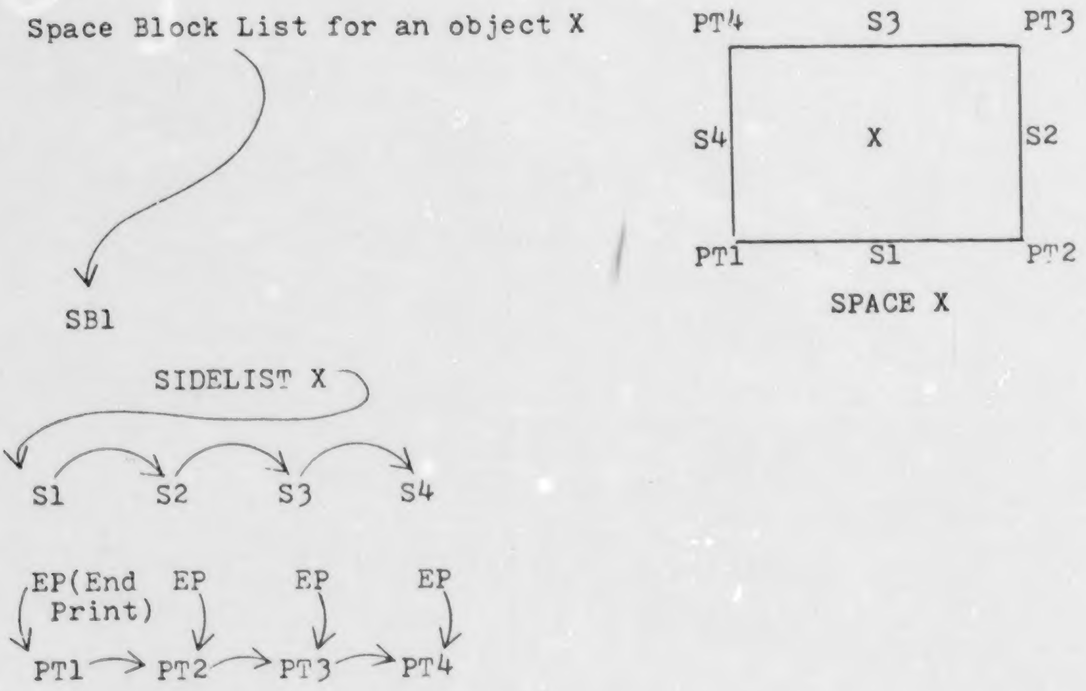
Space Block List for an object X
SB1
SIDELIST X
S1
S2
S3
S4
EP(End Print)
EP
EP
EP
PT1
PT2
PT3
PT4
PT4
S3
PT3
S4
X
S2
PT1
S1
PT2
SPACE X

Figure 5-5

With the exception of curvilinear objects, virtually any shape can be represented as a set of convex polygons. Orientation and dimensions, however, are not explicit and must be computed. Manipulation of the data structure is a relatively time consuming procedure. Furthermore, as in all of the other structures discussed thus far, the space-subspace relationship is not explicitly represented in DPS--a factor which might not necessarily affect the processes for which these structures have been implemented, but turns out to be an important factor in the design of elementary school spaces.

In examining alternative approaches it becomes evident that for every floorplan problem there is a unique representation. That is, the differences in the objectives and constraints of the research involving a floorplan results in the development of data structures particular to the solution of problems with such criteria. Thus it is not surprising that in the course of the present research a data structure suitable to the requirements and constraints of the analysis of space use in elementary schools, has yielded an appropriate representation.

5.3.3 A Tree Structured Representation for School Floorplans

To satisfy the requirements in this section, a tree* structured representation of floorplans was developed (see Figure 5-6). Each node in the tree represents a well defined domain on the floorplan. In the diagram solid lines between nodes define the space-subspace (tree-subtree) relationship, and the dashed lines depict internal linkages between nodes. If a set of spaces S_j, $j=1,\ldots,n$ are subspaces of S, then $\bigcup_{j=1} S_j \subseteq S$ and $S_i \cap S_j = \emptyset$, $i \neq j$. That is, if a space is subdivided, it is subdivided with no overlapping subspaces.

In its internal representation are four structural links; left, right, down, and back. A down link connects a root to a subtree, each element of which is a member of a two-way linked list connected by the left and right links. The back link from each node points to its root. Thus the internal structure is a back-linked binary tree representation of a tree.

In addition to the links, each node contains a pointer to a list of properties of the space and a data field which can be used to keep track of the status of the space.

---

*A tree is a finite set of one or more nodes such that a) there is one specially designated node called the root of the tree; and b) the remaining nodes are partitioned into m 0 disjoint sets $T_1,\ldots,T_m$ each of which is a tree. $T_1,\ldots,T_m$ are called subtrees of the root. [18 p. 305].

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TREE REPRESENTATION OF FLOORPLAN

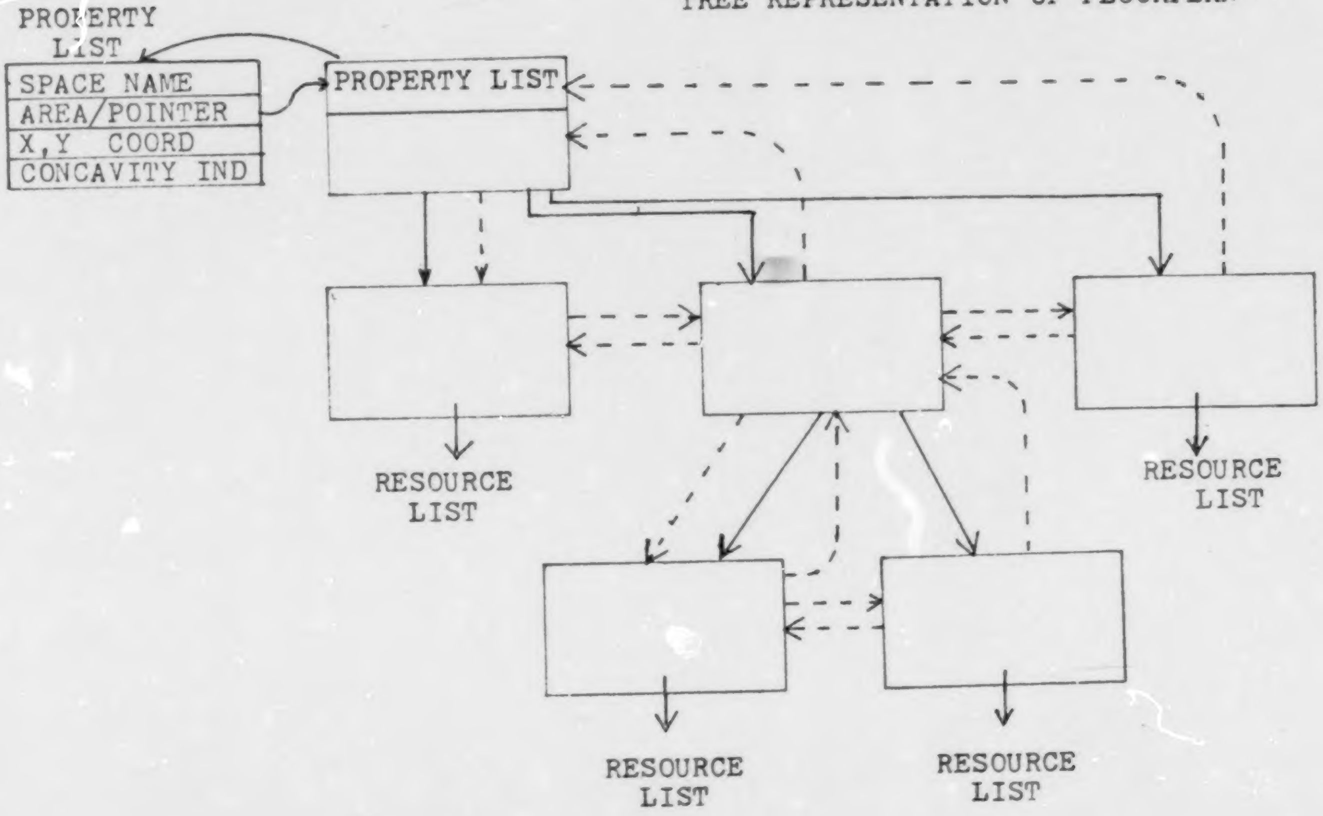
PROPERTY LIST
SPACE NAME
AREA/POINTER
X,Y COORD
CONCAVITY IND
PROPERTY LIST
RESOURCE LIST
RESOURCE LIST
RESOURCE LIST
RESOURCE LIST

Figure 5-6

The property list consists of:

1) the name of the space represented by the node
2) the area of the space
3) the x,y coordinates of the space
4) an indicator of the convexity or concavity of the space

The data field, which is 12 bits in length indicates 1) whether or not the space is currently in use and 2) whether or not the space is a terminal space (i.e., is a terminal node).

Terminal nodes represent the lowest level subspaces on the floorplan. From a terminal node, the down link points to a list of resources contained in that subspace--an inventory of furniture and equipment. The inventory of any node in the tree can be computed by backing up the resource lists of the terminal nodes of the subtrees of the node and summing across items.

One additional feature of this data structure is that the set of property lists pointed to from nodes in the tree is in itself an inverted list, each member of which points back to its associated node in the tree. This

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[*] A terminal node is a node which has no successors, i.e., a space which has no subspaces.

inverted list is sorted on area and thus allows entry into the space tree directly at a node whose area may satisfy one of the constraints on an activity.

5.4 An Example of a Floorplan Represented by the Tree Structure

In this section an example is given to show how a relatively simple floorplan can be represented by the structure described in Section 5.3.

Figure 5-7 shows a rectangular space A00 with three first level subspaces--A10, A11, and A12, defined by solid lines. Each of these is in turn subdivided into two spaces, and in the case of A21 and A24, further subareas are defined--A30, A31, and A32. Furniture and equipment in each space is also shown.

In Figure 5-8 the tree representing this floorplan is shown. For each space there is a unique node and in each node is the pointer to its associated property list. The down-link of each of the terminal nodes points to its resource list.

To obtain the set of resources for a space, a preorder traversal* of the subtree whose root is the node representing that space is made. At each terminal node (indicated by a bit set in the data field of the node) the resources are accumulated, thereby compiling an inventory of the space. For example, the contents of space A10 are

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*See [18], p. 316.

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SPACE A00

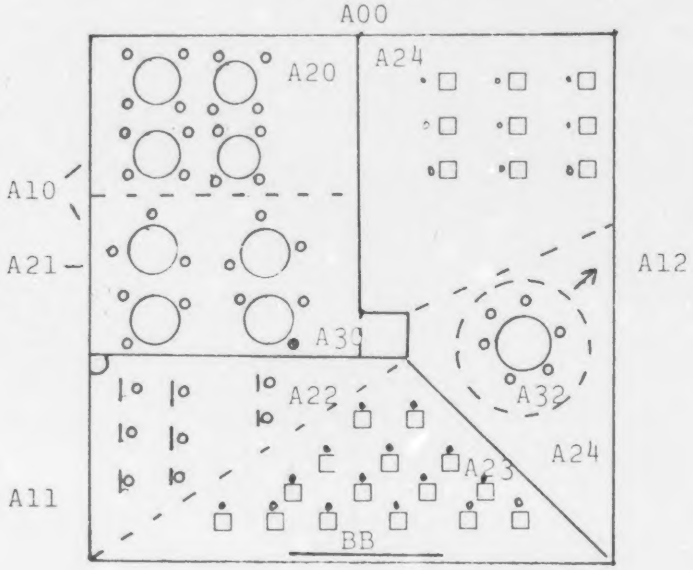
A00
A20
A24
A10
A21
A12
A30
A22
A32
A23
A24
A11
BB

Figure 5-7

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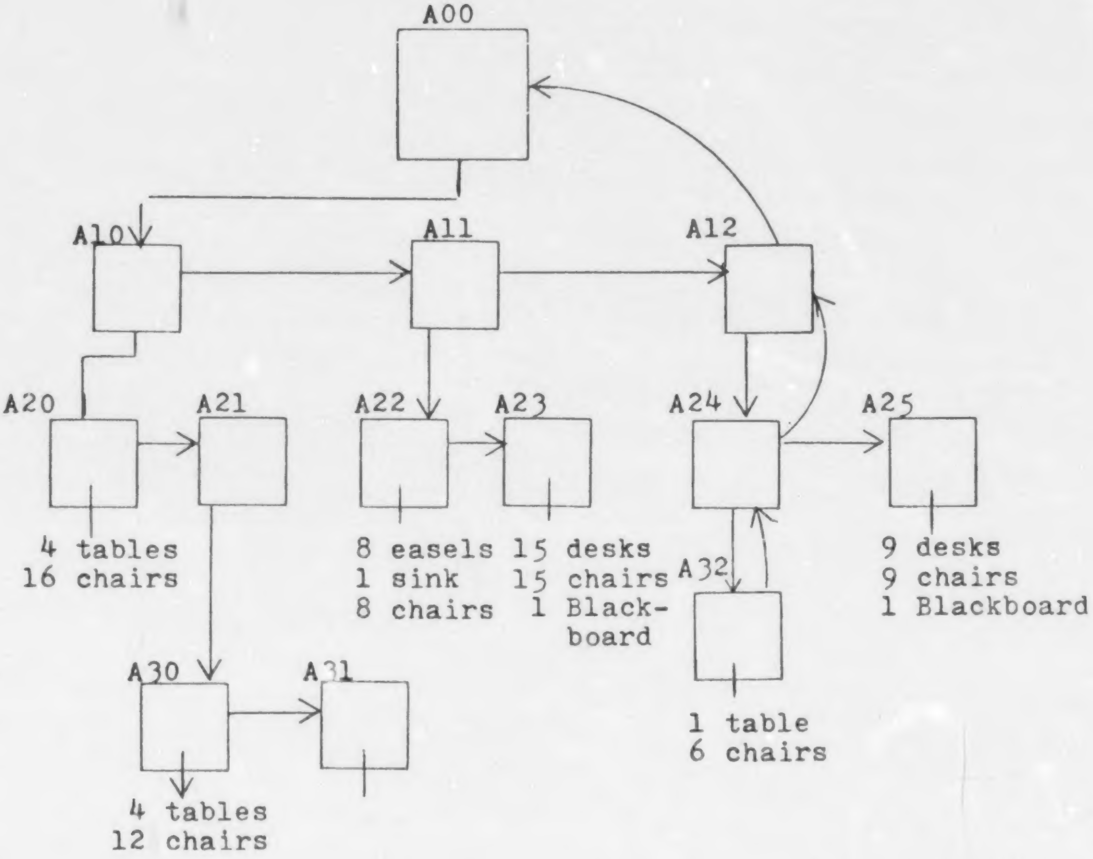
A00
A10
A11
A12
A20
A21
A22
A23
A24
A25
4 tables
16 chairs
8 easels
1 sink
8 chairs
15 desks
15 chairs
1 Blackboard
A32
9 desks
9 chairs
1 Blackboard
A30
A31
1 table
6 chairs
4 tables
12 chairs

Tree Representation of Space A00

Figure 5-8

obtained by starting at node A10 in the tree and visiting nodes A20, A21, A30 and A31, the preorder sequence of those nodes. A20 and A30 are marked as terminal nodes, and their resources are combined to yield 8 tables and 28 chairs and 2 blackboards which is the inventory of equipment and furniture of space A10.

When a space becomes occupied or released by an activity, its subspaces, and the spaces which contain it must be flagged to show they are or are not available for assignment. For example, if space A24 becomes occupied, A32, A12, and A00 can no longer be assigned activities. Following the back links in the tree from space A24, A12 and A00 are immediately accessible. Below A24, a preorder traversal of the subtree of which it is the root, visits all the affected subspaces of A24. In this example only A32 is visited.

Finally, the structure as depicted allows for a heuristic approach to the problem of determining proximity relationships among spaces. The idea is that spaces in the same subtree are more likely to be closer together than spaces in different subtrees. Furthermore, the deeper the descent is into the tree, the stronger the probability that two spaces on the same level are close together. This naturally follows from the fact that subtrees represent the subdivision of a space. The lower the level at which a given subtree starts the smaller the area of the space represented by its root.

For example, in Figures 5-7 and 5-8 it is clear that A24 and A25, siblings in the same subtree, are closer together than A24 and A20. This heuristic does not always work, however, considering that A20 is further from A31 (in its own subtree) than A23 is. Nevertheless, the application of this heuristic can provide the assignment program some reasonable guesses at appropriate spaces in situations where a close proximity relationship is required between two or more activities.

5.5 Discussion

The structure described satisfies the four general requirements specified in Section 5.3.2. Properties of a space are directly accessible from its node in the tree. Resources of a space are indirectly accessible from non-terminal nodes by descending to all of the terminals below the given node and accumulating all of the resources on the respective resource lists. This feature avoids redundant information being represented in the tree since, of course, some subset of the resources of a space must appear in one or more of its subspaces.

The space-subspace relationship is manifest in the structure of the tree by the definition of a tree. Whenever a space is assigned to an activity, neither its subspaces nor the spaces which contain it can be assigned. Thus when the assignment of a space is made, the status of affected spaces must be updated to reflect that fact. This is easily accomplished using standard algorithms for the traversal of a binary tree.

Finally, a proximity relationship between spaces can be determined in two ways. One is to compute distances or adjacencies between spaces using the coordinates of those spaces. Another way is to utilize the fact that as spaces are subdivided and represented in the tree, the lower the level of depth of a given subspace, the closer it will likely be to its siblings on the same level. As noted, this is a heuristic method of estimating proximity since there are indeed cases where two subspaces of the same space can be further apart than two spaces at a higher level in the tree hierarchy of spaces.

The property list, inverted on area, is of great usefulness because the most important requirement of an activity is that its space-area needs be satisfied. Thus, a list of prospective spaces for an activity may be compiled which meet the area requirement, and with a pointer to the tree, the status of each space can be ascertained without searching. Finally, the implementation of a set of list processing routines makes it easy to add or remove nodes from the tree or to update information contained therein.

The representation described is not without its limitations. Perhaps the major limitation is the requirement that the input floorplan be a partitioned space with mutually exclusive subspaces. That is, no space can be partially contained by more than one space, nor can overlapping spaces by represented. Such a situation can occur in practice when a space is located on the common boundary of two other spaces as is space C in Figure 5-9.

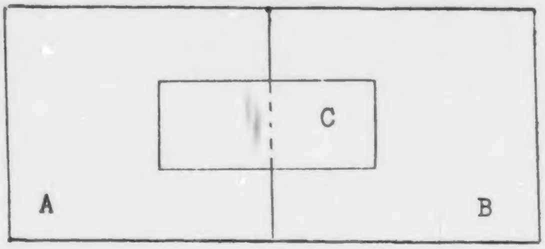

Figure 5-9

To implement a capability for the representation of the above mentioned spatial cases would require that the tree be generalized to a graph. In view of the fact that in all of the spaces observed during data collection, no spaces were recorded as overlapping, it was not felt that the graph structure was worth implementing at this stage of the research.

One other limitation in the representation is that adjacencies between spaces are not explicitly represented. Building this capability into the structure could be done relatively easily, however, by adding to the property list of each node, a list of adjacent spaces. The major use of adjacency information would lie in the ability of the system to build new spaces out of existing subspaces in which to assign activities. Since such a capability is not existent in the present version of the system, it was not felt necessary to build explicit adjacency information into the floorplan representation.

5.6 Summary

A binary tree representation for school floorplans has been presented in which each node corresponds to a space on the input floorplan. Access to the nodes can be made either by traversing the tree in the standard way or through any element in the set of property lists associated with each node.

This structure makes most of the information necessary for deciding where to place activities, given their space and resource requirements directly accessible to the simulation program. In the next chapter, an algorithm which makes use of this information to make assignments of spaces to activities is formally described.

CHAPTER 6

THE ASSIGNMENT OF ACTIVITIES TO SPACES

6.1 Introduction

6.1.1 General Introduction

In this chapter a formal description of the problem of assigning elementary school activities to appropriate spaces is presented and a solution is offered.

Assigning activities to spaces is a critical operation in the simulation because it is from the results of such an assignment that space use figures for a proposed school floorplan are derived. This problem involves a set of activities competing at a particular time on the schedule for a set of available spaces. Feasible solutions to the problem, if any exist, are solutions which satisfy a set of criteria or constraints on the problem. A function may also be defined such that the feasible solution which minimizes this function is said to be an optimal solution. As will be shown, however, certain conditions exist in this particular problem which make it unfeasible to find optimal solutions by any known methods.

One alternative to solving complex problems rigorously is to define heuristics which can lead to reasonable solutions to a problem but which can possibly miss better ones. Heuristics are generally used when a rigorous solution is impossible or impractical (e.g., in terms of computing costs). Considering that in the elementary schools observed in the course of this study, space assignments were made by a teacher or a team of teachers studying a schedule and finding a reasonable space for each activity, optimal solutions were not necessarily likely to be found.

6.1.2 Alternative Approaches to Assigning Space to Activities

Two approaches to the assignment of educational space were considered in the course of this research. The first was a derivative of an area of research known as the computer design of layouts. Computer design of layouts includes factory design or plant layout problems, printed wiring board layouts and other floorplan layout problems including hospitals, airports and to some extent, schools. These problems are defined by 1) a 2-dimensional surface with no previously defined spaces on it, 2) a set of objects to be placed on the surface, and 3) constraints on the placement of the objects.

Factory layout constraints, for example, are usually defined by the flow paths required for the manufacture of the items being produced. That is, the parts and products involved in manufacturing an item must proceed through a sequence of operations (the sequence depends on the final product) before the final product is completed. The costs involved in moving materials through a system can vary substantially with the location of the manufacturing facilities for an item. When many items, all requiring different production flow paths are manufactured, the operating efficiency of a factory can be greatly affected by the layout of facilities; and the greater the number of facilities to be located, the more difficult it is to find an optimal solution[6].

The second approach considered, and the one eventually pursued, involves the assignment of activities into spaces whose boundaries are specified on the floorplan and the resources of the spaces are defined. Linear programming methods exist which will solve classes of such problems.

The linear programming assignment problem is represented by a set of m objects which must be placed into a set of m locations according to certain restrictions in such a way as to minimize a cost function. Typically, the problem is set up as follows: Define a matrix of objects and locations with a cost c_{ij} as the ij^{th} entry in the matrix. Let x_{ij} be the assignment of object i to location j (x_{ij} is referred to as a decision variable). The question is, then, what values of x_{ij} $(i=1,2,...,m;$

$j=1,2,\ldots,m)$ minimize $\sum_{i=1}^{m} \sum_{j=1}^{m} c_{ij} x_{ij}$, the total cost function. Standard algorithms exist (see [14], pp. 198-204) which will find an optimal solution from the initial matrix representation of the assignment problem.

One major factor mitigates against the use of linear programming techniques to make the final assignments of activities to spaces--in the set of spaces available for activities at a given time there may be a space-subspace relationship among some of the members in that set. Some problems which have this characteristic can be solved using integer programming methods, but usually only if they contain small numbers of assignments, and even then computing costs are quite high.

Another factor to be considered is that spaces are often subdivided into a large number of subspaces, only a subset of which would likely satisfy the requirements of a particular activity. The linear programming approach considers all spaces at all times until a final assignment is made.

In light of these factors and the consideration that the simulation is to show how space will likely be used in a school floorplan (which is to say, not necessarily optimally) a heuristic approach is used to make the assignment of spaces to activities.

In the following sections a statement of the assignment problem as it pertains to this research is presented, followed by a description of a heuristic approach taken to derive solutions to the problem, and finally, the algorithm used to perform the assignment operation is given.

6.2 A Formal Statement of the Assignment Problem for School Floorplans

At a given time step in the simulation there exists either no scheduled activities or there exists a set of activities which require space.

Let $A = \{a_1, a_2, \ldots, a_n\}$ be the set of activities. For the set of activities, A, there exists a set of constraint vectors, C, where

$$C = \{(c_{11}, c_{12}, \ldots, c_{1r}), \ldots, (c_{n1}, c_{n2}, \ldots, c_{nr})\}$$

and c_{ij} = the j^{th} constraint on the i^{th} activity. Constraints consist of requirements for furniture and equipment resources, specifications on the space required, and priority to be given to an activity which may result in an earlier assignment for that activity.

Let $S = \{S_1, S_2, \ldots, S_k\}$ be the set of spaces available for assignment such that

$$\forall\ i, j \leq k \text{ and } i \neq j,\ S_i \cap S_j = \emptyset \text{ or}$$
$$(S_i \subset S_j \text{ and } S_j \not\subset S_i) \text{ or } (S_j \subset S_i \text{ and}$$
$$S_i \not\subset S_j)$$

That is, any pair of spaces is either mutually exclusive or one is a proper subspace of the other.

For S there exists a set R of resource vectors such that

$$R = \{(r_{11}, r_{12}, \ldots, r_{1m}), \ldots, (r_{k1}, r, \ldots, r_{km})\},$$

and r_{ij} is the j^{th} resource of the i^{th} space.

The problem is to find a mapping from $A \rightarrow S$ such that the set of constraints C is satisfied by R.

6.3 What is a Satisfactory Assignment?

At this point the question arises as to what kind of assignment is indeed satisfactory. Criteria for job shop layout problems, for example, are quite specific. A cost function can be accurately determined for each placement of an activity into a space. The arrangement of activities into spaces so as to minimize total cost of producing a product satisfies the criteria for the assignment. This is not necessarily the case in an elementary school. Although some criteria for activity placement can be rather specific (e.g., number of desks and chairs required), other criteria is more subjective, such as priority. In particular some characteristics of an activity may take it desirable for that activity to have the first choice of available spaces--hence, a higher priority for being processed than other activities.

Two kinds of priority are recognized by the simulation system. These are referred to as explicit priority and implicit priority. Explicit priority is a value given to an activity which indicates how important it is that the activity takes place at the scheduled time. Special events such as all-school assemblies, invited speakers for a class, examinations and other similar activities comprise the majority of events which can be assigned explicit priorities.

Implicit priority is an internally generated priority which reflects the relative importance of an activity based on some elements in the set of requirements for an activity. Implicit priority can be based on equipment requirements such as pianos for music activities or easels for art activities. It can also represent the extent of use to which the resources required by a space will be put. The measure of this extent of use is the quantity "student-minutes" calculated by multiplying the number of students participating in an activity by its duration in minutes. That is, an activity which has a larger number of students and/or will last a longer period of time should have access to an available space prior to an activity which will use the space less time or with fewer students.

Priority is a constraint which affects the order in which activities are assigned and thus gives a better choice of spaces to higher priority activities. The other constraints, namely, area required, furniture and equipment required, distraction factor, and nature of the activity are constraints on the size, resources, location, and shape of a space. Area, furniture and equipment are self-explanatory as to the requirements they place on a space. Distraction factor can place a restriction on the location of an activity by requiring that it be isolated from other activities by walls or by distance. If the nature of an activity is group (supervised or unsupervised), then the space to which it is assigned should have a shape which allows a line of sight between any two points in the space.

It is not likely that at assignment time there will be a set of spaces which will perfectly match the requirements set down by the scheduled activities. Of the spaces available, however, some measure of the degree to which each space will satisfy an activity can be computed. If each activity could then be assigned to its best choice or highest ranking space based on this measure, this could be said to be the optimal assignment of activities to spaces.

It is possible, however, that several activities will find that one particular space is their best choice. A decision must be made in this case to deprive all but one of the activities of their most desirable space. A satisfactory assignment of activities to spaces is thus seen as a relative matter. What can be done, however, is to evaluate the worth of a space to an activity and define heuristics to provide a reasonable assignment of activities to spaces.

6.4 A Heuristic Approach to the Assignment of Activities to Spaces

6.4.1 Heuristics and Human Information Processing

In the absence of methodologies which are guaranteed to provide optimal or correct solutions to a problem, heuristics can often be employed to provide useful results.

The heaviest use of heuristics is in the area of artificial intelligence where researchers have attempted to emulate human abilities in game-playing, theorem proving and problem solving programs. A good example of a heuristic is in Newell, Simon, and Shaw [26] where, to generate the proof of a theorem, they work backwards from the theorem to the axioms using theorems or previously proved valid logical rules to generate lines in the proof. By this method, they are guaranteed that if one of their generated lines is the same as an axiom or previous theorem, then they will have generated a valid proof of the theorem. There is no guarantee, though, that they will ever attain a proof. They are assured that they have narrowed the search compared to starting with an axiom or theorem and generating lines hoping to get to the theorem to be proved.

Problems can often be represented in the form of a tree where at each node there exists a number of alternative actions that can be followed. If the tree is fully diagrammed (which can only be done practically for small or trivial problems such as the game of tic-tac-toe), and a solution to the problem exists, then one or more of the terminal nodes will represent a set of solutions. A path can then be traversed from the root of the tree to one of the terminals, yielding a problem solution as a sequence of steps (nodes in the tree). When the entire tree cannot be represented, as in the game of checkers, for example, heuristics can be employed which eliminate alternative steps which will be unlikely to yield a winning sequence. One such method is to assign a score to each of the alternatives using arbitrary criteria and to follow only those branches which, by virtue of their scores, seem promising. An evaluation polynomial which algebraically combines the criteria is a common way to compute the scores of the alternatives from a node.

The worth of such heuristics is in their ability to reduce the number of alternative paths to the solution of a problem at a relatively small cost in terms of possible undesirable choices. Lindsay and Norman [21] describe the selection of a move by chess master as taking place in two phases: an exploration phase, during which less promising moves are weeded out, and a verification phase in which the validity of the remaining moves is determined. Decisions during these two phases are guided by a set of criteria or priorities, a combination of which can be attributed to a given move.

Thus, a parallel can be drawn between mechanized heuristic methods and human problem solving behavior. Both attempt to narrow the search for a solution to a problem by reducing the alternative paths at each step of the way.

6.4.2 Problem Solving Processes in the Assignment of Activities

A set of heuristic processes can be defined for assigning activities to spaces. Two of these are analogous to the exploration and verification phases of decision making described in Section 6.4.1. In particular, given the sets A of activities and S of available spaces, there are four processes involved in an assignment:

1. Eliminate high priority activities. This is a pre-processing step which makes immediate assignment of high explicit priority activities. Processes 2, 3, and 4 operate on the remaining activities.
2. Exploration Phase. Reduction of the number of alternative spaces for each activity based on high significance criteria.
3. Verification Phase. Evaluation of the degree to which each of the remaining alternative spaces satisfies each activity
4. Assignment Phase. Resolution of conflicts (activities competing for the same space) and final assignment.

The first process is applied to the set of activities ordered on explicit priorities. Activities with explicit priority are assigned one by one to the spaces which best suits them. Spaces are evaluated using the procedures to be described in process three.

In process two the set of alternative spaces to which an activity can be assigned is reduced by selecting for consideration only those spaces whose area lies within a certain range of the required area. Since space is the most important commodity, this procedure prevents the assignment of an activity to a space which is either too small to allow the activity to function or which is so big that to make such an assignment would result in a very inefficient use of space. It would be even more inefficient, if, in the latter case, an activity for which the space was well suited were scheduled before the space was released and given a less satisfactory assignment.

To each of the remaining spaces being considered by an activity, process three assigns a score based on the percentage of agreement between the requirements established for the activity and the resources supplied by the space. this score is computed by a procedure which is explained in the next section. The spaces for each activity are then sorted on score.

The final process examines the space lists for each activity starting with the highest valued spaces. If a space is at the top of only one activity's list, it is assigned to that activity. A space which is at the top of two or more lists is assigned to the activity which would suffer most by not obtaining that space.

Whenever a space is assigned a housekeeping function is initiated to remove it, its subspaces, and the hierarchy of spaces which contain it from every other space list for activities remaining to be assigned. This is because a space and one of its subspaces may not be assigned to different activities simultaneously.

These processes, explained in the next section, are iterated at each time step.

6.4.3 An Algorithm for Assigning Activities to Spaces

In this section a description of the method for assigning activities to spaces is presented. The method proceeds following the four processes described in the previous section. The process of eliminating high priority activities is accomplished through an exhaustive search of available spaces for each activity and utilizes as its criterion for assignment the best score obtained from the scoring polynomial as described in the verification phase. This process is not explained in further detail.

For the remainder of the processes the following algorithm, presented informally, is used for the computation of an assignment.

Algorithm ASGSPC (Assign Spaces)

As before let $A = \{a_1, a_2, \ldots, a_n\}$ be the set of activities scheduled at some given time t. Let $S = \{s_1, s_2, \ldots, s_k\}$ be the set of spaces available with the space-subspace relationship as described in Section 6.2. The sets C and R, constraints and resources, are also defined to the algorithm.

Corresponding to the problem solving processes the algorithm takes place in three stages; R-Reduction of Alternatives, V-Verification, and A-Assignment.[1]

Stage R - Reduce Alternatives

1. For each activity $a \in A$: Initialize the acceptable range of areas of spaces at ± 16% of the area constraint on a_i.

2. Compile from the list of unoccupied spaces in S, the set of spaces, S^*, whose area is within the tolerance computed in Step 1. If S^* has less than 2 entries do the following steps;

---

[1] The programmed implementation of this algorithm performs portions of the individual steps in a slightly different order but with equivalent results. The description of the algorithm in this form is presented for its clarity.

2a Increase the acceptable range of spaces. The upper bound is increased exponentially until it reaches a maximum of 300%. The lower bound is increased at regular intervals until it reaches a maximum of 50%.

2b If the limits in 2a have been reached, continue, otherwise return to the beginning of step 2.

S^* will be called the list of potential spaces to which the activity may be assigned. Flag all concave spaces in S^*.

3. Examine the value for the "nature of the activity" constraint. If supervised group or unsupervised group (working as a group), eliminate from S^* spaces which have been flagged as being concave.[1] Go to Stage V.

Stage V - Verify Alternatives

For each activity $A_j \in A$, $j=1,n$

1. Compute a score for each space on the potential space list S^*. The computation of the score is as follows: For a_j define a vector CON and a vector RES each of the same length. Each element of CON represents one of the set of possible constraints on activity a_j, and each element of RES represents one of the set of possible resources which must be present in the space for the corresponding element of CON to be satisfied. That is,

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[1] This step is not implemented in the programmed version of the algorithm.

the i^{th} element of CON corresponds to the i^{th} element of RES. $CON_i = 1$ implies constraint i is in effect. $RES_i = 1$ implies resource i is in the space. CON_i and RES_i are 0 otherwise.

Let $Q(CON_i)$ = the quantity or value of the constraint represented by the i^{th} element of CON.

$Q(RES_i)$ = the quantity or value of the resource represented by the i^{th} element of RES.

$SCORE_{kj}$ = the score of the k^{th} space in the potential space list of a_j.

In addition, for each element of RES, there exists a list ALT of up to ℓ alternative resources in order of usefulness (the list may be empty). This list is referenced in the event that a space does not have a required resource.

The following algorithm then computes the score for the space:

Algorithm SCRSPC (Compute the Score for a Space)

1. Check constraint vector: For CON_i and RES_i, $i=1,2,\ldots,m$

   a. if $CON_i = 1$ and $RES_i = 1$, go to Step 2

   b. if $CON_i = 1$ and $RES_i = 0$, go to Step 3

   c. if $CON_i = 0$ go to beginning of Step 1 (i.e., reiterate this step for the next value of i).

2. Compute cumulative score:

$$SCRSPC \leftarrow SCRSPC + 1 - \left(\frac{|Q(CON_i) - Q(RES_i)|}{Q(CON_i)}\right)$$

3. Default: Let m_i be the number of elements in ALT_i (the list of alternative resources of RES_i .) Set $P \leftarrow 1$. If $m_i = 0$, return to Step 1. Otherwise, set $M \leftarrow 1$. While $M \leq m_i$ do Steps a, b, and c.

   a. Set $P = P - .2$ (P represents the relative value of the alternative being considered compared to the original requirement.)

   b. If $RES_1 > 0$ Set

$$SCRSPC \leftarrow SCRSPC + P\left(1 - \frac{|Q(CON_1) - Q(RES_i)|}{Q(CON_1)}\right)$$

   and return to Step 1.

   (Note: $Q(CON_1)$ is the quantity or value of CON_1 if it had been specified as the original requirement for the activity. That is, if tables are an alternative furniture item for desks, then the quantity of tables required for some number of students would differ from the quantity of desks.

   c. Set $M \leftarrow M+1$. Go to a.

   The value of $1 - \left(\frac{|Q(CON_i) - Q(RES_i)|}{Q(CON_i)}\right)$ is a measure of the percentage of agreement of the quantity or value of a constraint for an activity and its corresponding resource in the space. For example, suppose for some activity 9 chairs were required and there were 12 chairs in the space being evaluated. Let CON_1 and RES_1 refer to "desks", and $P_1 = 1$. Then $CON_1 = 9$, $RES_1 = 12$ and

$$P_1\left(1 - \frac{|Q(CON_i) - Q(RES_i)|}{Q(CON_i)}\right) = 1 \cdot \left(1 - \frac{|9-12|}{9}\right)$$

$$= 0.667 .$$

Once scores have been computed for each space on S^* two further operations are performed. First, S^* is sorted into descending score order. Then, starting with the space at the top of the list, any subspaces or superspaces of that space are eliminated from the rest of the list. This procedure is repeated for what is then the second space in the list and subsequently thru the next to the last space on S^*.

When the potential space lists for each activity to be assigned have been scored and processed, the final assignment process begins.

STAGE A - Assignment of Spaces to Activities

The set of activities $\{a_1, a_2, \ldots, a_n\}$ and their processed potential space lists S_i^* $(i=1,2,\ldots,n)$ are the inputs to algorithm ASGACT which makes the assignment of activities to spaces. The set A of activities is sorted into descending order of student minutes (number of students x duration in minutes). Let $SPACE_{i1}$ and $SPACE_{i2}$ be the first and second ranked spaces on S_i^*, and let $SCORE_{i1}$ and $SCORE_{i2}$ be their scores.

The list A is processed iteratively by looking at the highest priority activity, say a_k, which is yet unassigned. Define CLISTS = $\{CLIST_1, CLIST_2, \ldots, CLIST_{n-1}\}$

such that $CLIST_k = a_k \cup A'$; and A' is a proper subset of $\{a_{i+1}, \ldots, a_n\}$ such that the top ranked space on the S^* lists for each element in $CLIST_k$ is the same. ACT_i^k is defined to be the activity represented by the i^{th} entry in $CLIST_k$. $CLIST_k$, then, is the set of activities which have the same first choice space while a_k is being processed. Note that $CLIST_{k+1}$ is undefined until a_k has been processed. Whenever $A' \neq \emptyset$ (i.e., is null), a_k is assigned to its top ranked space, and the next iteration begins.

For each $CLIST_k$ define $SPACE_{ir}^k$ as the r^{th} ranking space for the activity which is the i^{th} entry in $CLIST_k$. Similarly, $SCORE_{ir}^k$ is the score of the r^{th} ranking space for the activity which is the i^{th} entry in $CLIST_k$. Define $DIFF = \{DIFF_1, DIFF_2, \ldots, DIFF_{n-1}\}$ corresponding to CLISTS. Each $DIFF_k$ is a list of differences between the first and second ranked spaces on the S^* for each activity in $CLIST_k$. Finally ACT_i^k is defined to be the activity represented by the i^{th} entry in $CLIST_k$.

Algorithm ASGACT - Assign Activities to Spaces

For $i = 1, 2, \ldots, n$ do the following steps

1. If $(i+1) > n$, assign a_i to $SPACE_{i1}$ and terminate the algorithm. Otherwise, proceed to Step 2.

2. (Check for activities competing for same space.) Place a_i into conflict list $CLIST_i$ and set $COUNT \leftarrow 1$.

For $j = i+1,\ldots,n$, if $SPACE_{i1} = SPACE_{j1}$, add a_j to the conflict list and set $COUNT \leftarrow COUNT+1$.

3. (See if any conflicts.) If $COUNT > 1$ proceed to Step 4, otherwise assign a_i to $SPACE_{i1}$ and to to Step 6.

4. (Compute difference scores for competing activities.) For $m = (1,2,\ldots,COUNT)$ compute $DIFF_{im} = SCORE^{i}_{m1} - SCORE^{i}_{m2}$.

5. (Resolve conflicts and make assignment.) Sort CLIST into descending order of DIFF. That is, place the activity whose difference score is the greatest at the top of the list, the next greatest second, etc. Assign ACT^{ki}_{1} to $SPACE^{i}_{11}$. (Give the activity with the greatest difference score its top-ranked space.)

6. (Housekeeping.)

a. For $SPACE^{i}_{11}$ flag all subspaces and superspaces and remove them from S^{*} for every other activity left to be processed in A . This is to prevent the subsequent assignment of a subspace or superspace of an already assigned space.

b. If $ACT^{i}_{1} \neq a_i$ (Note-the sequence of activities in $CLIST_i$ can change during the sort performed in Step 5.), remove it from A and pack A . Then return to Step 1.

Upon the conclusion of ASGACT, the assignments of activities to spaces at a given time t are completed.

In summary, then, ASGACT looks at each activity in order of its student minutes requirement and determines if the top ranked space is the same as that of any of the other activities. If not, the activity is assigned its top ranked space. If conflicts exist, then the difference between the scores of the two top ranked spaces on each list are examined. The activity for which this difference is greatest is assigned its top ranked space using the reasoning that it would suffer the most by having to accept its second ranked choice. This decision process iterates until all assignments have been made. Some examples of the assignment process are given in Appendix D.

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6.5 Discussion

6.5.1 Some Properties of the Assignment Algorithm

In this section some properties of the assignment algorithm are presented which may not be readily apparent from the preceding description. These have to do mainly with what the algorithm does under certain limiting conditions.

It is possible that on initial entry into ASGACT that one or more potential space lists will contain only one element. If that is the case, then, the computation in Step 4 will not be meaningful. Therefore, whenever there is only one space in an activity's list, $SCORE^{i}_{m2}$ is set to -10,000 before Step 4 is executed. This number is great enough so that the difference between it and $SCORE^{i}_{m1}$ will be larger than the difference score between the two top spaces of any other conflicting activity's list. If, for two or more activities competing for the same space, the potential space list has only one element, the activity for which the space has the highest absolute score will be assigned to the space. The other activities will not be assigned to any space since their lists will become empty when updated to reflect the previous assignment.

Another factor of interest is that in the computation of the score for a space the magnitude of the score is dependent on the number of constraints. For example, consider a space with five resources. Suppose two activities have specified that space on their respective potential space lists. The first activity specifies only one resource requirement while the second needs four of the five. If the space meets the requirements for both activities exactly, its score for the second will be higher than the first since the scoring algorithm produces a cumulative score based on the fit between each constraint and its associated resource. Currently, this information is used in the event that several activities are competing for the same space and that space is the only one on their potential space lists. Otherwise it is used only to order the potential spaces for an activity and to compute the difference scores. While it might seem that an activity can be assigned a space with a lower score for it than for another activity, and will therefore waste resources, this is not necessarily the case. In fact, a space which scores high because its resources match an activity very well will often have a significantly higher score than the second best space. An activity with low resource requirements will probably not acquire a space list with as widely disparate scores since the range will necessarily be lower. Thus, the activity for which the space scores the highest--absolutely--will likely be assigned to that space. On the other hand, when the difference score for the two top spaces of an activity with high resource requirements is low, then the activity isn't losing much by being assigned to its second best space, if this happens to become the case.

CHAPTER 7

RESULTS OF THE SIMULATION FOR SELECTED TEST CASES

7.1 Introduction

In this chapter the results of simulations for selected test cases are presented and analyzed. A prototype system was implemented incorporating most, but not all of the design criteria specified in Chapters 4, 5, and 6. Specifically, two criteria for the assignment of activities to spaces are not included in the current version of the system: 1) the distraction factor is not considered in the location of activities relative to one another and 2) the criteria for the shape of a space is not employed in the process of selecting potential spaces for an activity.

The simulation program in its present form generates a large colume of hard copy output. Therefore, only one test case will be presented in its entirety. Selected portions of other test cases will be shown to illustrate specific features.

All the tests were performed using a data base derived from the observation of School A and the floorplans of Schools A and B.

7.2 The Test Cases

7.2.1 Objective

The major objective in running the simulation was to show how the results can be used in evaluating a school floorplan. It should be recalled that the system is designed to be an aid to the architect, and, that in itself, it does not determine the success or failure of a floorplan. The information it does supply, however, can be shown to be of use in making decisions about the amounts and types of spaces that have been designed on a given floorplan.

Several factors were considered in designing the test cases to be discussed in this chapter. First, it was necessary to establish some benchmark so that the validity of the simulation could be ascertained. Given the quality of the data collected at School A and its relatively complex floorplan, it was felt that a simulation of School A on its own floorplan would provide a rigorous test for the simulation system. More specifically, it was known that School A could be operated with at least its planned enrollment (150 students per pod). Theoretically, the simulation program should be able to emulate this in terms of generating schedules, assigning students to activities, and assigning activities to spaces. With a benchmark thus established, experiments could be performed with the simulation to answer questions about the functionality of an input floorplan.

In this chapter, the following three questions about the schools observed in this study were considered representative of the ways the system could be used:

1. How would School A function if its enrollment were increased by 1/3.
2. If certain spaces are seen to be underused, how would their removal affect the overall ability of School A to provide space for activities.
3. What would result if the model for School A were used in a simulation on the floorplan of School B--e.g., a multiunit methodology on a traditional floorplan.[1]

Three test runs were made to provide data with which to answer these questions and to establish the benchmark. These are described in Table 7-1a.

Since the observed data from School A was the most reliable, the multiunit methodology was specified in each of the simulations. In addition, keeping the methodology constant provided a good base for comparing the performance of the floorplans of Schools A and B. The block schedule (Table 7-1b) and the MODL parameter were also kept constant so as that comparisons could be made between floorplans while using the same generated schedule.

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[1] Quasi-traditional would be more accurate since the original floorplan design was totally open-space. As can be seen from Figure 7-2, however, the space was organized, using partitions, as an egg-crate design.

Test run one provided the benchmark. It was dne in optimal mode with 150 students and a multiunit methodology. One pod (C00) from School A was selected as the input floorplan. Its structure (Figure 7-1) was derived from observation. For test cases involving School B, an equivalent area (Area A) was selected as the input floorplan. Its structure is shown in Figure 7-2. Each of these floorplans is a large open space subdivided into the areas depicted by the dotted and dashed lines. In School B (Figure 7-2) the internal solid lines indicate moveable (but which were never observed to change) partitions. No partitions were observed in School A.

7.2.2 Preliminary Information for the Test Cases

This section is provided to give the reader information which is not directly presented in the output from the simulation program and to aid in reading the output shown in this chapter.

For the two input floorplans Tables 7-2 and 7-3 give the areas and detail the inventories of each space and subspace for reference purposes. The spaces are organized roughly into counter clockwise order as they appear on the

TABLE 7-1a

TEST RUNS FOR THE SIMULATION

Run	School	Floorplan	Enrollment	MODL	Methodology	Mode
1	School A	Unit 2 (Pod C)	150	10 min.	multiunit	optimal
2	School A	Unit 2	200	10 min.	multiunit	optimal
3	School B	Area A	150	10 min.	multiunit	optimal

TABLE 7-1b

BLOCK SCHEDULE FOR THE TEST CASES

09:00 - 10:30	MATH
10:30 - 11:30	LARTS
11:30 - 13:00	SCI

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School A - Pod C

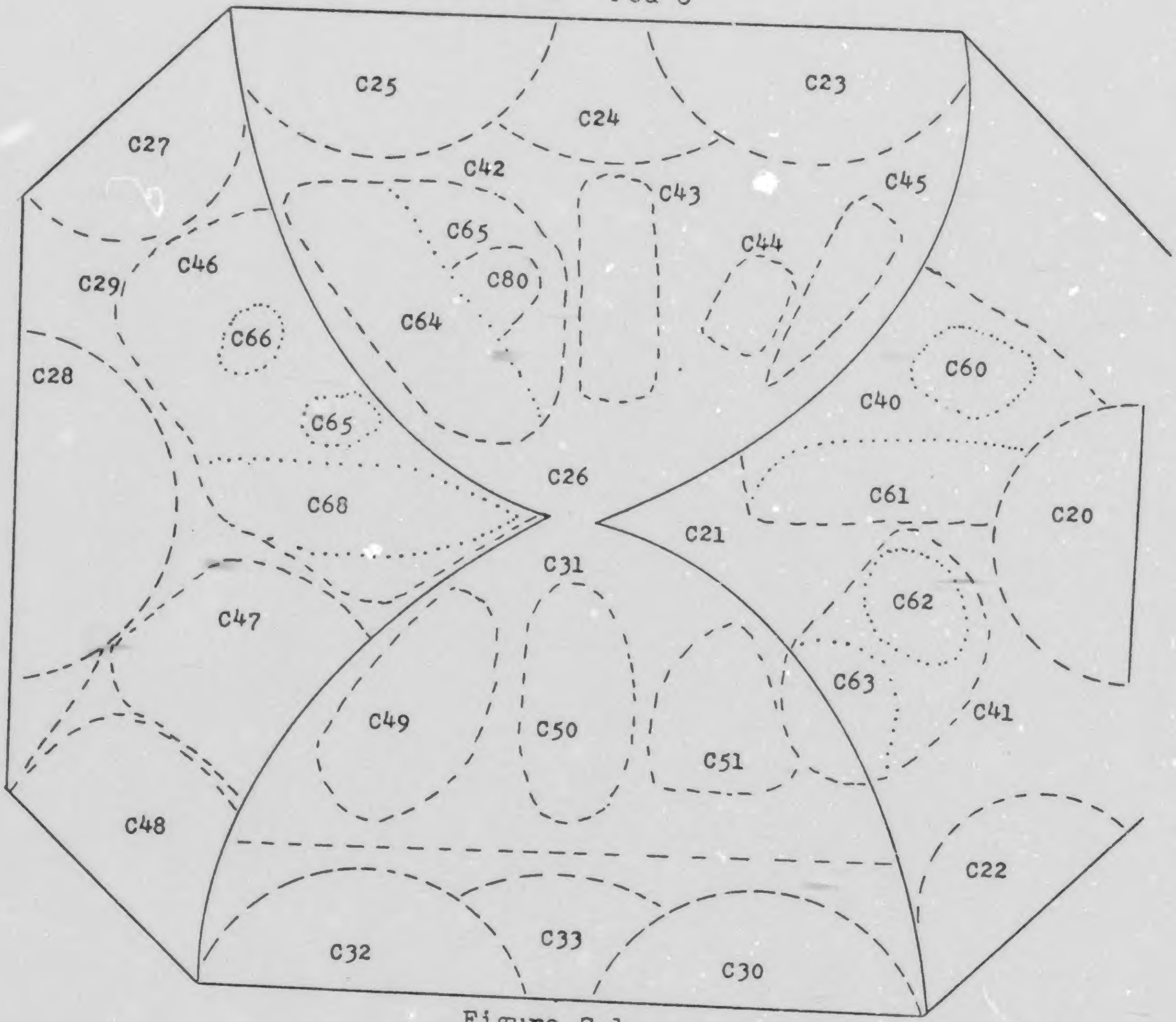
C25
C24
C23
C27
C42
C43
C45
C65
C44
C46
C29
C80
C64
C66
C60
C28
C40
C65
C26
C61
C68
C20
C21
C31
C62
C47
C63
C41
C49
C50
C51
C48
C22
C33
C32
C30

Figure 7-1

School B - Area A

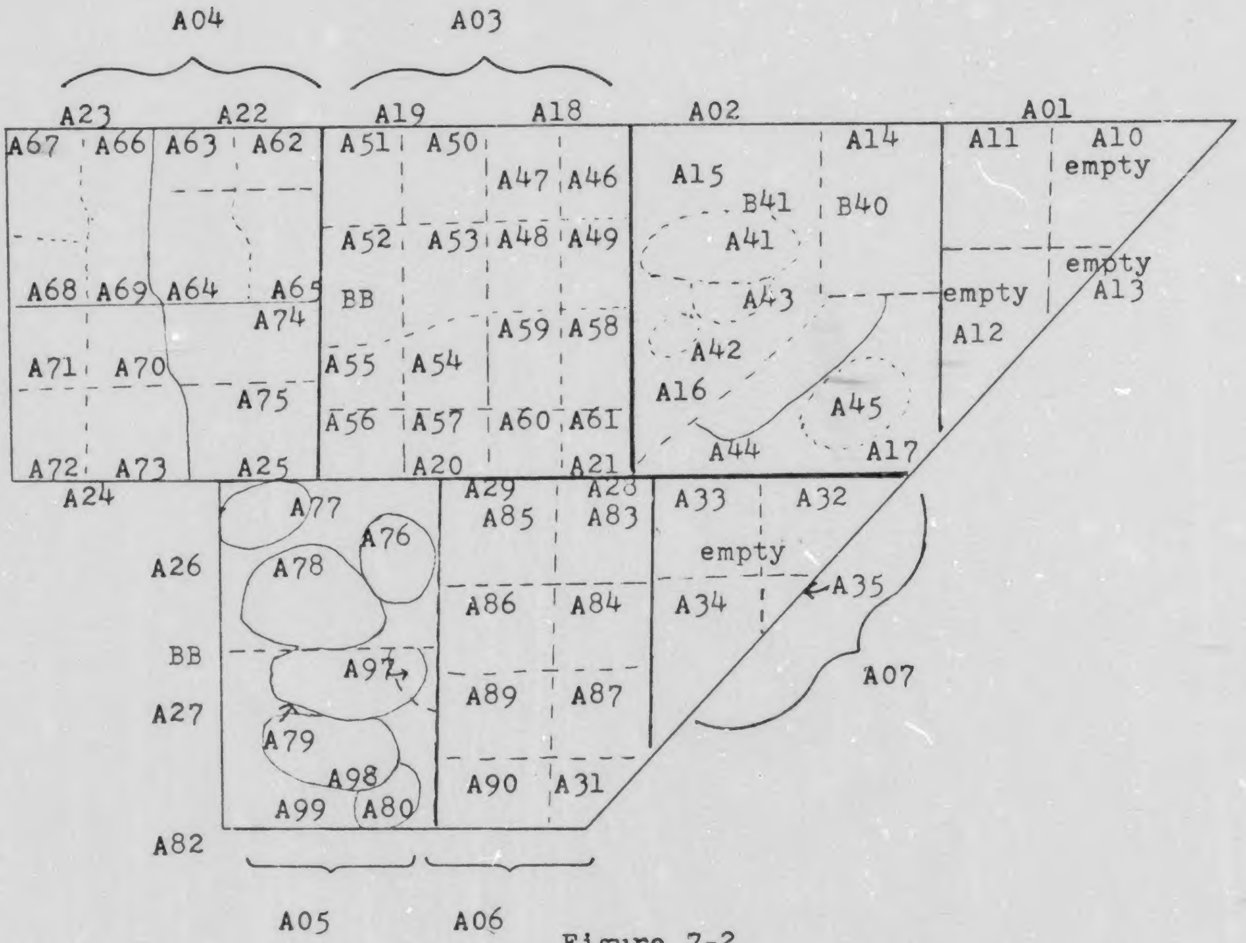
A04
A03
A23
A22
A19
A18
A02
A01
A67
A66
A63
A62
A51
A50
A47
A46
A15
A14
A11
A10
empty
B41
B40
A41
A68
A69
A64
A65
A52
A53
A48
A49
BB
A43
empty
empty
A13
A12
A74
A59
A58
A42
A71
A70
A55
A54
A16
A45
A75
A56
A57
A60
A61
A44
A17
A72
A73
A25
A20
A21
A24
A29
A28
A33
A32
A77
A85
A83
A76
empty
A26
A78
A86
A84
A34
A35
BB
A97
A07
A89
A87
A27
A79
A98
A90
A31
A99
A80
A82
A05
A06

Figure 7-2

TABLE 7-2

AREAS AND INVENTORIES* OF SPACES FOR SCHOOL A, POD C

Space	Area	Desks	Tables	Chairs	BB	MS	MP	TV	SI
C00	7025	173	6	210	18	1	1	3	3
C10	1815	48		48	2			2	
C20	232				1				
C21	1486	48		48				2	
C40	391	30		30				1	
C60	43	8		8				1	
C61	143	22		22					
C41	204	18		18				1	
C62	164	12		12				1	
C63	52	6		6					
C22	144				1				
C11	1865	53		53	2				2
C23	235				1				1
C24	130								
C25	264				1				1
C26	1230	23		23					
C42	344	25		25					
C64	204	22		22					
C65	142	3		3					
C80	35	3		3					
C43	109	12		12					
C44	41	6		6					
C45	61	10		10					
C12	1461	38	1	42	3	1	1	1	
C27	165				1				
C28	312				1	1	1		
C29	1254	38	1	42	1			1	

Legend: BB = Blackboards, MS = Movie Screens, MP =
MP = Movie Projectors, TV = Television Sets,
SI = Sinks

---

*Note--the inventories will not total correctly because an item which is in the subspace of a space is in the space itself.

TABLE 7-2

(Continued)

Space	Area	Desks	Tables	Chairs	BB	MS	MP	TV	SI
C66	24	3		3					
C67	18	3		3					
C68	193	24		24					
C47	251	8	1	12					
C48	203				1			1	
C13	1758	34	5	67	2				1
C30	203		2	2	1				1
C31	1095	34	3	55					
C49	159	18	1	23					
C50	139	16		24					
C51	119								
C52	29		2	8					
C32	201				1				
C33	126								

TABLE 7-3

AREAS AND INVENTORIES OF SPACES IN SCHOOL B, AREA A

Space	Area	Desks	Tables	Chairs	BB	BP	MS	MP
A00	4220	146	8	223	14	5	1	1
A01	309	5		5	1			
A10	109							
A11	94	5		5	1			
A12	88							
A13	12							
A02	788	29	1	36	2	2		
A14	153				1			
A40	19				1			
B40	135							
A15	217	9		9	1			
A41	46	9		9	1			
B41	145							
A16	128	4		4				
A42	11	2		2				
A17	269	16	1	23		2		
A44	64	14		14	1			
A45	61	2	1	9		1		
A03	794	28	1	41	3	1		
A18	173	8		8	1			
A46	46				1			
A47	51	4		4				
A48	32	4		4				
A49	32							
A19	221	6	1	19	1	1		
A50	64		1	6		1		
A51	54							
A52	57			7	1			

Legend: BB = Blackboards, BP = Portable Blackboards,
MS = Movie Screen, MP - Movie Projector

TABLE 7-3

(Continued)

Space	Area	Desks	Tables	Chairs	BB	BP	MS	MP
A53	48	6		6				
A20	175	8		8				
A54	50	8		8				
A55	35							
A56	34							
A57	41							
A21	157	6		6	1			
A58	42				1			
A59	42	6		6				
A60	28							
A61	31							
A04	788	37	2	49	4			
A22	190	7		7	1			
A62	34							
A63	35							
A64	62	7		7				
A95	30	7		7				
A65	51				1			
A23	189	4	1	10	1			
A66	66	4		4				
A96	27	4		4				
A67	61							
A68	31		1	6	1			
A69	24							
A24	218	14	1	20	1			
A70	56	6		6				
A71	44	1	6	1				
A72	44							
A73	67	8		8				
A25	172	12		12	1			
A74	86	5		5				
A75	80	7		7	1			

TABLE 7-3

(Continued)

Space	Area	Desks	Tables	Chairs	BB	BP	MS	MP
A05	565	14	4	49		2	1	1
A26	273		2	23		1	1	1
A76	27		1	6		1		
A77	16		1	5				
A78	63			12			1	1
A27	278	14	2	26		1		
A79	62	3		3				
A97	17	3		3				
A80	16							
A81	57		1	8				
A98	28	6		6				
A99	27	5		5				
A82	25		1	4		1		
A06	494	33		43	4	1		
A28	130	13	13		1			
A83	66	8		8	1			
A84	68	5		5				
A29	141	8		18	2			
A85	84	8		8	1			
A86	58			10	1			
A30	104	6		6				
A87	61	6		6				
A88	46							
A31	92	6		6	1			
A89	60	6		6	1			
A90	32							
A07	242							
A32	65							
A33	74							
A34	83							
A35	10							

floorplan and all of a space's subspaces follow it before the next major space. No inventory figures are given for a space which has no furniture or equipment.

On the output listing for a simulation run, the information is organized into five parts; 1) the parameters, 2) the block schedule, 3) the generated schedule, 4) summary information of space use at each time period, and 5) an end-of-the-day summary.

Preceding the summary at each time period is a list of the activity sections which will begin at that time, their generated characteristics and furniture and equipment requirements. This list is presented in decreasing order of the student minutes requirement.

7.3 Simulation Examples

7.3.1 Introduction

In this section, examples of simulations are presented. The first, Test Run 1, establishes the validity of the system. The rest of the section is devoted to an analysis of the various test runs as they pertain to the four questions posed in Section 7.2.2.

7.3.2 Test Run 1

The output for Test Run 1 with the inputs and parameters described earlier is presented in the next several pages. The block schedule (Table 7-1b) is a representative schedule of activities with two exceptions. First, no time was allocated for lunch, since it was assumed instructional space would not be used at that time. Thus, the schedule was compacted. Second, no special activities or activities which would normally occur in separate specialized space were included. This would have meant removing a certain number of students from the pool of available students, i.e., fewer students in the pod during those times. It was felt that a more rigorous test of the program would result if the full complement of students were available throughout the day.

The detailed schedule of activities generated from the schedule of blocks of time allocated for instructional activities is shown in Table 7-4. Its conformance with the model described in Chapter 3 should be noted. Math and Science tended to have larger groups and therefore fewer sections than Language Arts. (Language Arts was allocated only one hour whereas Math and Science each were allocated 90 minutes. Conceivably, Language Arts would have had several more sections given the extra 30 minutes.) Nevertheless, considerable dispersion of group sizes is found in all three activities. A comparison is invited between the schedule generated and that which was observed at School A. Examples of the subdivision of blocks of time for Language Arts and Math in Pod C00 are shown in Tables 7-5 and 7-6. The groupings of students and durations of the activities appear to compare favorably with that generated by the computer programs for a similar amount of time. Some differences were that 1) at the obser ved school all of the students assigned to a Pod or an Area would not necessarily be available for assignment to activities at all times, and 2) slightly longer blocks than were observed were defined for the activities on the input block schedule. The latter was true for certain observed periods but not in general, however.

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TABLE 7-4

TEST RUN 1

SCHEDULE OF ACTIVITIES

START TIME	END TIME	ACTIVITY	SEC. NO.	NO. STUD.
9:00	10:10	MATH	1	9
9:00	9:10	MATH	2	20
9:00	9:10	MATH	3	28
9:00	9:10	MATH	4	17
9:00	10:10	MATH	5	28
9:00	9:10	MATH	6	48
9:10	9:30	MATH	7	17
9:10	9:40	MATH	8	8
9:10	9:40	MATH	9	3
9:10	9:40	MATH	10	17
9:10	9:40	MATH	11	27
9:10	10:20	MATH	12	25
9:10	9:20	MATH	13	5
9:10	9:40	MATH	14	11
9:20	9:30	MATH	15	5
9:30	10:00	MATH	16	22
9:40	10:30	MATH	17	3
9:40	9:50	MATH	18	17
9:40	10:10	MATH	19	46
9:50	10:00	MATH	20	17
10:00	10:10	MATH	21	39
10:10	10:30	MATH	22	17
10:10	10:30	MATH	23	35
10:10	10:30	MATH	24	8
10:10	10:30	MATH	25	16
10:10	10:30	MATH	26	17
10:10	10:30	MATH	27	3
10:10	10:20	MATH	28	5
10:10	10:30	MATH	29	21
10:20	10:30	MATH	30	4
10:20	10:30	MATH	31	3
10:20	10:30	MATH	32	20
10:20	10:30	MATH	33	3
10:30	10:40	LARTS	1	25
10:30	10:40	LARTS	2	125
10:40	11:10	LARTS	3	28
10:40	11:00	LARTS	4	3
10:40	11:00	LARTS	5	5
10:40	10:50	LARTS	6	15
10:40	11:10	LARTS	7	18
10:40	11:20	LARTS	8	16

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10:40	10:50	LARTS	9	7
10:40	11:00	LARTS	10	6
10:40	11:00	LARTS	11	9
10:40	11:00	LARTS	12	8
10:40	10:50	LARTS	13	8
10:40	11:10	LARTS	14	9
10:40	11:30	LARTS	15	7
10:40	10:50	LARTS	16	9
10:40	11:00	LARTS	17	2
10:50	11:20	LARTS	18	34
10:50	11:10	LARTS	19	5
11:00	11:30	LARTS	20	7
11:00	11:20	LARTS	21	9
11:00	11:20	LARTS	22	17
11:10	11:30	LARTS	23	7
11:10	11:20	LARTS	24	6
11:10	11:30	LARTS	25	47
11:20	11:30	LARTS	26	7
11:20	11:30	LARTS	27	24
11:20	11:30	LARTS	28	11
11:20	11:30	LARTS	29	6
11:20	11:30	LARTS	30	3
11:20	11:30	LARTS	31	3
11:20	11:30	LARTS	32	3
11:20	11:30	LARTS	33	13
11:20	11:30	LARTS	34	6
11:20	11:30	LARTS	35	3
11:20	11:30	LARTS	36	3
11:30	11:50	SCI	1	24
11:30	11:50	SCI	2	17
11:30	12:10	SCI	3	22
11:30	11:50	SCI	4	29
11:30	12:50	SCI	5	58
11:50	12:10	SCI	6	28
11:50	12:20	SCI	7	31
11:50	12:10	SCI	8	11
12:10	12:40	SCI	9	5
12:10	12:30	SCI	10	40
12:10	12:30	SCI	11	16
12:20	12:40	SCI	12	31
12:30	12:40	SCI	13	11
12:30	12:50	SCI	14	16
12:30	12:40	SCI	15	29
12:40	13:00	SCI	16	28
12:40	13:00	SCI	17	11
12:40	13:00	SCI	18	24
12:40	13:00	SCI	19	13
12:50	13:00	SCI	20	34
12:50	13:00	SCI	21	34
12:50	13:00	SCI	22	6

TABLE 7-5

SCHEDULE OF LANGUAGE ARTS SUBACTIVITIES
SCHOOL A, POD C

Start Time	End Time	Subject	Sec. No.	No. Students
8:35	9:20	LARTS	1	15*
8:35	8:45	LARTS	2	9
8:35	9:15	LARTS	3	40*
8:35	8:45	LARTS	4	15*
8:35	8:45	LARTS	5	45*
8:45	9:05	LARTS	6	9
8:45	9:25	LARTS	7	2
8:45	9:25	LARTS	8	100*
8:45	9:25	LARTS	9	5
9:10	9:25	LARTS	10	15*
9:10	9:25	LARTS	11	15*
9:10	9:25	LARTS	12	9
9:10	9:25	LARTS	13	9

---

*These figures are within ±5 of the observed number.

TABLE 7-6

SCHEDULE OF MATH SUBACTIVITIES
SCHOOL A POD C

Start Time	End Time	Subject	Sec. No.	No. Students
9:25	9:35	MATH	1	40*
9:25	9:55	MATH	2	5
9:25	9:45	MATH	3	25*
9:25	9:45	MATH	4	45
9:25	9:40	MATH	5	50*
9:25	9:45	MATH	6	30*
9:35	9:55	MATH	7	3
9:35	9:55	MATH	8	5
9:35	9:50	MATH	9	5

---

*These figures are within ±5 of the observed number.

Following the generated schedule, the output listing alternates between the description and requirements of activities scheduled to begin at each time step and the summary information which is printed upon completion of the assignment of activities to spaces at that time (Table 7-7). The former are sorted and presented in order of student minutes and thus represent the implicit priority ordering described in Chapter 6.

At the first time step (9:00) six sections of math are scheduled to start. According to the generated schedule, Section 5 has 28 students; its characteristics include the circular configuration, a distraction factor[*] of 3, and requirements for 28 desks, 28 chairs, 2 TV's and 448 square feet of space. The summary table at the end of the requirements listing shows that at 9:00, Math Section 5 was assigned to space C40 which has 30 desks, 30 chairs, and 1 TV. The area of C40 is 391 square feet and the ratio of space required to space used is 1.15. Section 1 which requires 2 tables, 9 chairs and a blackboard is 216 square feet of space C30 which has 2 tables, 12 chairs, a blackboard and

---

[*] Note--the distraction factor is not currently utilized by the assignment algorithm.

203 square feet. Section 6 which requires 48 chairs, and 48 desks is located into Space C47 which does not adequately meet the seating requirements (8 desks, 1 table, and 12 chairs) but is a closer match of the area requirement than other spaces which have the required seating. Because the selection process of the assignment algorithm is oriented towards matching area requirements as opposed to furniture (the assumption being that much modern school furniture is portable), discrepancies in seating between the activity requirements and resources in the space are not that uncommon in the program.

After the assignment summary the total space required and space used during the time period is printed. The figure for space used should be examined with respect to the spaces which were assigned. An activity assigned to a space which is a subspace of a larger space in some sense utilizes all of the larger space unless other activities are assigned to other subspaces of the larger one. Another factor which should be taken into account is that without intervening walls a certain amount of circulation space and buffer space between assigned activities is desirable (e.g., corresponding to corridor space in the traditionally designed school). This figure will range from 15-30% of the total instructional space designed for

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TABLE 7-7

TEST RUN 1
ACTIVITY REQUIREMENTS AND ASSIGNMENT SUMMARIES

```
  ACTIVITY = MATH    SECTION   5  REQUIREMENTS.
 CONF= CIR       DF=3  AREA REQ.=   448
   28 DESK        28 CHAIR
    2 TV

  ACTIVITY = MATH    SECTION   1  REQUIREMENTS.
 CONF= CLU       DF=1  AREA REQ.=   216
    2 TABLE        9 CHAIR
    1 BB

  ACTIVITY = MATH    SECTION   6  REQUIREMENTS.
 CONF= RAD       DF=4  AREA REQ.=   288
   48 DESK        48 CHAIR
    3 TV

  ACTIVITY = MATH    SECTION   3  REQUIREMENTS.
 CONF= CLU       DF=2  AREA REQ.=   672
    5 TABLE       28 CHAIR
    2 TV

  ACTIVITY = MATH    SECTION   2  REQUIREMENTS.
 CONF= CLU       DF=1  AREA REQ.=   400
   20 DESK        20 CHAIR
    1 BB

  ACTIVITY = MATH    SECTION   4  REQUIREMENTS.
 CONF= CIR       DF=4  AREA REQ.=   408
   17 UNIFORM
    1 BB



TIME... 9:00

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 MATH      5      28        449       C40    391   1.15
 MATH      1       9        216       C30    203   1.06
 MATH      2      20        400       C42    344   1.16
 MATH      6      48        288       C47    251   1.15
 MATH      3      28        672       C46    568   1.18
 MATH      4      17        409       C28    312   1.31

AREA REQUIRED    2432 SQ. FT.   AREA  USED    2069 SQ.FT.
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```
 ACTIVITY = MATH    SECTION  12  REQUIREMENTS.
CONF= CLU        DF=3  AREA REQ.=    500
  25 DESK          25 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION  11  REQUIREMENTS.
CONF= CLU        DF=1  AREA REQ.=    648
   5 TABLE         27 CHAIR
   2 TV

 ACTIVITY = MATH    SECTION  10  REQUIREMENTS.
CONF= FMI        DF=3  AREA REQ.=    340
   3 TABLE         17 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION   7  REQUIREMENTS.
CONF= CLU        DF=2  AREA REQ.=    340
  17 DESK          17 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION  14  REQUIREMENTS.
CONF= CLU        DF=2  AREA REQ.=    220
  11 DESK          11 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION   8  REQUIREMENTS.
CONF= CLU        DF=1  AREA REQ.=    160
   8 DESK           8 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION   9  REQUIREMENTS.
CONF= CLU        DF=2  AREA REQ.=     60
   3 DESK           3 CHAIR
   1 TV

 ACTIVITY = MATH    SECTION  13  REQUIREMENTS.
CONF= CLU        DF=1  AREA REQ.=    100
   5 DESK           5 CHAIR
   1 BB
```

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```
TIME... 9:10

ACTIVITY  SEC.  NO.STD.  AREA REQ.  SPACE  AREA  REQ;USED
 MATH      12     25        500      C42    344   1.45
 MATH      11     27        648      C46    568   1.14
 MATH      10     17        340      C47    251   1.35
 MATH       7     17        340      C28    312   1.09
 MATH      14     11        220      C20    232    .95
 MATH       8      8        160      C62    164    .98
 MATH       9      3         60      C63     52   1.15
 MATH      13      5        100      C51    119    .84
 MATH       1      9        216      C30    203   1.06
 MATH       5     28        448      C40    391   1.15

AREA REQUIRED    3032 SQ. FT.   AREA  USED    2634 SQ.FT.

 ACTIVITY = MATH   SECTION  15  REQUIREMENTS.
CONF= FMI      DF=4  AREA REQ.=    50
   5 DESK          5 CHAIR
   1 BB
```

```
TIME... 9:20

ACTIVITY  SEC.  NO.STD.  AREA REQ.  SPACE  AREA  REQ;USED
 MATH      15      5         50      C44     41   1.22
 MATH       1      9        216      C30    203   1.06
 MATH       5     28        448      C40    391   1.15
 MATH       7     17        340      C28    312   1.09
 MATH       8      8        160      C62    164    .98
 MATH       9      3         60      C63     52   1.15
 MATH      10     17        340      C47    251   1.35
 MATH      11     27        648      C46    568   1.14
 MATH      12     25        500      C42    344   1.45
 MATH      14     11        220      C20    232    .95

AREA REQUIRED    2982 SQ. FT.   AREA  USED    2558 SQ.FT.

 ACTIVITY = MATH   SECTION  16  REQUIREMENTS.
CONF= FMI      DF=2  AREA REQ.=   220
  22 DESK         22 CHAIR
   1 BB
```

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```
TIME... 9:30

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 MATH      16     22        220      C23    235     .94
 MATH       1      9        216      C30    203    1.06.
 MATH       5     28        448      C40    391    1.15
 MATH       8      8        160      C62    164     .98
 MATH       9      3         60      C63     52    1.15
 MATH      10     17        340      C47    251    1.35
 MATH      11     27        648      C46    568    1.14
 MATH      12     25        500      C42    344    1.45
 MATH      14     11        220      C20    232     .95

AREA REQUIRED   2812 SQ. FT.   AREA  USED   2440 SQ.FT.

  ACTIVITY = MATH   SECTION  19  REQUIREMENTS.
 CONF= FMI       DF=1  AREA REQ.=    460
   46 DESK          46 CHAIR
    1 BB

  ACTIVITY = MATH   SECTION  18  REQUIREMENTS.
 CONF= CLU       DF=2  AREA REQ.=    340
   17 DESK          17 CHAIR
    1 BB

  ACTIVITY = MATH   SECTION  17  REQUIREMENTS.
 CONF= CLU       DF=1  AREA REQ.=     60
    3 DESK           3 CHAIR
    1 BB


TIME... 9:40

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 MATH      19     46        460      C46    568     .81
 MATH      18     17        340      C28    312    1.09
 MATH      17      3         60      C63     52    1.15
 MATH       1      9        216      C30    203    1.06
 MATH       5     28        448      C40    391    1.15
 MATH      12     25        500      C42    344    1.45
 MATH      16     22        220      C23    235     .94

AREA REQUIRED   2244 SQ. FT.   AREA  USED   2105 SQ.FT.

  ACTIVITY = MATH   SECTION  20  REQUIREMENTS.
 CONF= CLU       DF=1  AREA REQ.=    408
    3 TABLE         17 CHAIR
    1 BB
```

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```
TIME... 9:50

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 MATH      20     17        408      C28    312    1.31
 MATH       1      9        216      C30    203    1.06
 MATH       5     28        448      C40    391    1.15
 MATH      12     25        500      C42    344    1.45
 MATH      16     22        220      C23    235     .94
 MATH      17      3         60      C63     52    1.15
 MATH      19     46        460      C46    568     .81

AREA REQUIRED    2312 SQ. FT.   AREA  USED    2105 SQ.FT.

 ACTIVITY = MATH   SECTION  21  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=   780
  39 DESK          39 CHAIR
   1 BB


 TIME...10:00

 ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
  MATH      21     39        780      C31   1095     .71
  MATH       1      9        216      C30    203    1.06
  MATH       5     28        448      C40    391    1.15
  MATH      12     25        500      C42    344    1.45
  MATH      17      3         60      C63     52    1.15
  MATH      19     46        460      C46    568     .81

 AREA REQUIRED    2464 SQ. FT.   AREA  USED    2653 SQ.FT.

 ACTIVITY = MATH   SECTION  23  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=   700
  35 DESK          35 CHAIR
   1 BB

 ACTIVITY = MATH   SECTION  29  REQUIREMENTS.
CONF= CIR      DF=1  AREA REQ.=   336
  21 DESK          21 CHAIR
   1 BB

 ACTIVITY = MATH   SECTION  26  REQUIREMENTS.
CONF= CLU      DF=3  AREA REQ.=   340
  17 DESK          17 CHAIR
   1 BB

 ACTIVITY = MATH   SECTION  22  REQUIREMENTS.
CONF= CLU      DF=2  AREA REQ.=   340
  17 DESK          17 CHAIR
```

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```
 ACTIVITY = MATH    SECTION  25  REQUIREMENTS.
CONF= CLU       DF=3  AREA REQ.=   384
   3 TABLE          16 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION  24  REQUIREMENTS.
CONF= CLU       DF=4  AREA REQ.=   192
   2 TABLE           8 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION  27  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   126
   3 NOFURN
   1 TV

 ACTIVITY = MATH    SECTION  28  REQUIREMENTS.
CONF= CIR       DF=2  AREA REQ.=    80
   5 DESK            5 CHAIR
   1 BB


 TIME...10:10

 ACTIVITY  SEC.  NO.STD.  AREA REQ.  SPACE  AREA  REQ:USED
  MATH      23     35        700      C29   1254    .56
  MATH      22     17        340      C40    371    .87
  MATH      29     21        336      C28    312   1.08
  MATH      25     16        384      C25    264   1.45
  MATH      26     17        340      C23    235   1.45
  MATH      24      8        192      C30    203    .95
  MATH      27      3        126      C33    126   1.00
  MATH      28      5         80      C45     61   1.31
  MATH      12     25        500      C42    344   1.45
  MATH      17      3         60      C63     52   1.15

 AREA REQUIRED   3058 SQ. FT.   AREA  USED     3242 SQ.FT.

 ACTIVITY = MATH    SECTION  32  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   400
  20 DESK           20 CHAIR
   1 BB

 ACTIVITY = MATH    SECTION  30  REQUIREMENTS.
CONF= CIR       DF=3  AREA REQ.=   128
   1 TABLE           4 CHAIR
   1 TV

 ACTIVITY = MATH    SECTION  31  REQUIREMENTS.
CONF= RAD       DF=3  AREA REQ.=    18
   3 DESK            3 CHAIR
   1 BB
```

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```
ACTIVITY = MATH    SECTION  33  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=    72
  1 TABLE          3 CHAIR
  1 3B


TIME...10:27

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
  MATH     32      20        400      C42    344    1.16
  MATH     30       4        128      C24    130     .98
  MATH     31       3         18      C52     29     .62
  MATH     33       3         72      C22    144     .50
  MATH     17       3         60      C63     52    1.15
  MATH     22      17        340      C40    391     .87
  MATH     23      35        700      C29   1254     .56
  MATH     24       8        192      C30    203     .95
  MATH     25      16        384      C25    264    1.45
  MATH     26      17        340      C23    235    1.45
  MATH     27       3        126      C33    126    1.00
  MATH     29      21        336      C28    312    1.08

AREA REQUIRED    3096 SQ. FT.   AREA  USED    3484 SQ.FT.
ACTIVITY = LARTS  SECTION    2  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=  2750
 125 CHAIR
  1 RB

ACTIVITY = LARTS  SECTION    1  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=   500
  25 DESK        25 CHAIR
  1 RB


TIME...10:30

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
  LARTS     2     125       2750      C13   1758    1.56
  LARTS     1      25        500      C46    568     .88

AREA REQUIRED    3250 SQ. FT.   AREA  USED    2326 SQ.FT.
```

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```
  ACTIVITY = LARTS  SECTION    3  REQUIREMENTS.
CONF= CLU       DF=1   AREA REQ.=    560
   28 DESK          28 CHAIR
    1 MS

  ACTIVITY = LARTS  SECTION    8  REQUIREMENTS.
CONF= CLU       DF=1   AREA REQ.=    384
    3 TABLE         16 CHAIR

  ACTIVITY = LARTS  SECTION    7  REQUIREMENTS.
CONF= CLU       DF=2   AREA REQ.=    396
   18 CHAIR

  ACTIVITY = LARTS  SECTION   15  REQUIREMENTS.
CONF= CLU       DF=2   AREA REQ.=    294
    7 NOFURN
    1 BB

  ACTIVITY = LARTS  SECTION   14  REQUIREMENTS.
CONF= CLU       DF=1   AREA REQ.=    180
    9 DESK           9 CHAIR
    1 TR

  ACTIVITY = LARTS  SECTION   11  REQUIREMENTS.
CONF= CLU       DF=1   AREA REQ.=    180
    9 DESK           9 CHAIR
    1 BB

  ACTIVITY = LARTS  SECTION   12  REQUIREMENTS.
CONF= CLU       DF=2   AREA REQ.=    192
    2 TABLE          8 CHAIR
    1 BB

  ACTIVITY = LARTS  SECTION    6  REQUIREMENTS.
CONF= CLU       DF=1   AREA REQ.=    360
    3 TABLE         15 CHAIR

  ACTIVITY = LARTS  SECTION   10  REQUIREMENTS.
CONF= CLU       DF=1   AREA REQ.=    132
    6 CHAIR
    1 BB

  ACTIVITY = LARTS  SECTION    5  REQUIREMENTS.
CONF= CIR       DF=1   AREA REQ.=     60
    5 DESK           5 CHAIR
    1 PP
```

```
 ACTIVITY = LARTS  SECTION  16  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=   378
   9 MOFURN
   1 BB

 ACTIVITY = LARTS  SECTION  13  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=   160
   8 DESK        8 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION   9  REQUIREMENTS.
CONF= CIR      DF=2  AREA REQ.=   224
   2 TABLE       7 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION   4  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=    60
   3 DESK        3 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION  17  REQUIREMENTS.
CONF= FMI      DF=3  AREA REQ.=    40
   1 TABLE       [illegible] CHAIR
   1 BB


TIME...10:40

ACTIVITY  SEC.  NO.STD.  AREA REQ.  SPACE  AREA  REQ:USED
  LARTS     3     23        560      C46    568     .99
  LARTS     6     15        360      C42    344    1.05
  LARTS     7     18        375      C40    391    1.01
  LARTS    16      9        378      C28    312    1.21
  LARTS     8     16        384      R000     0     .00
  LARTS    15      7        294      C25    264    1.11
  LARTS    12      8        192      C30    203     .95
  LARTS    14      9        180      C62    164    1.10
  LARTS    13      8        160      C27    165     .97
  LARTS    11      9        180      C32    201     .90
  LARTS    10      6        132      C22    144     .92
  LARTS     5      5         80      C45     61    1.31
  LARTS     9      7        224      C20    232     .97
  LARTS     4      3         60      C63     52    1.15
  LARTS    17      2         40      C44     41     .98

 AREA REQUIRED    4004 SQ. FT.   AREA  USED    3527 SQ.FT.
```

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```
ACTIVITY = LARTS  SECTION  18  REQUIREMENTS.
CONF= FMI        DF=2  AREA REQ.=    748
  34 NOFURN
  1 BB

ACTIVITY = LARTS  SECTION  19  REQUIREMENTS.
CONF= CLU        DF=1  AREA REQ.=    100
  5 DESK            5 CHAIR



TIME...10:50

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
  LARTS    18     34         748      C31   1075    .68
  LARTS    19      5         100      C33    126    .79
  LARTS     3     28         560      C46    563    .99
  LARTS     4      3          60      C63     52   1.15
  LARTS     5      5          80      C45     61   1.31
  LARTS     7     10         396      C40    391   1.01
  LARTS     8     16         384      9999     0    .00
  LARTS    10      6         132      C22    144    .92
  LARTS    11      9         180      C32    201    .90
  LARTS    12      8         192      C30    203    .95
  LARTS    14      9         180      C42    164   1.10
  LARTS    15      7         294      C25    264   1.11
  LARTS    17      2          40      C44     41    .98

AREA REQUIRED    3346 SQ. FT.   AREA USED    3310 SQ.FT.

ACTIVITY = LARTS  SECTION  22  REQUIREMENTS.
CONF= RAD        DF=2  AREA REQ.=    102
  17 DESK          17 CHAIR
  1 BB

ACTIVITY = LARTS  SECTION  20  REQUIREMENTS.
CONF= CLU        DF=1  AREA REQ.=    168
  2 TABLE           7 CHAIR
  1 BB

ACTIVITY = LARTS  SECTION  21  REQUIREMENTS.
CONF= FMI        DF=2  AREA REQ.=    198
  9 NOFURN
```

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```
TIME...11:00

ACTIVITY  SEC.   NO.STUD.    AREA REQ.    SPACE   AREA   REQ:USED
 LARTS     22      17           102        C43     109      .94
 LARTS     20       7           168        C30     203      .83
 LARTS     21       9           198        C32     201      .99
 LARTS      3      28           560        C46     568      .99
 LARTS      7      18           396        C40     391     1.01
 LARTS      8      16           384        0000      0      .00
 LARTS     14       9           180        C62     164     1.10
 LARTS     15       7           294        C25     264     1.11
 LARTS     18      34           748        C31    1095      .68
 LARTS     19       5           100        C33     126      .79

AREA REQUIRED    3130 SQ. FT.   AREA  USED    3121 SQ.FT.

 ACTIVITY = LARTS   SECTION  25  REQUIREMENTS.
CONF= CLU       DF=2  AREA REQ.=  1034
  47 CHAIR
   1 DP

 ACTIVITY = LARTS   SECTION  23  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   140
   7 DESK          7 CHAIR
   1 DB

 ACTIVITY = LARTS   SECTION  24  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   120
   6 DESK          6 CHAIR
   1 MS


TIME...11:10

ACTIVITY  SEC.   NO.STUD.    AREA REQ.    SPACE   AREA   REQ:USED
 LARTS     25      47          1034        C29    1254      .82
 LARTS     23       7           140        C22     144      .97
 LARTS     24       6           120        C65     142      .85
 LARTS      8      16           384        0000      0      .00
 LARTS     15       7           294        C25     264     1.11
 LARTS     18      34           748        C31    1095      .68
 LARTS     20       7           168        C30     203      .83
 LARTS     21       9           198        C32     201      .99
 LARTS     22      17           102        C43     109      .94

AREA REQUIRED    3188 SQ. FT.   AREA  USED    3412 SQ.FT.
```

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```
 ACTIVITY = LARTS  SECTION  27  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   576
   5 TABLE         24 CHAIR

 ACTIVITY = LARTS  SECTION  33  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   546
  13 NOFURN
   1 BP

 ACTIVITY = LARTS  SECTION  28  REQUIREMENTS.
CONF= CLU       DF=3  AREA REQ.=   242
  11 CHAIR

 ACTIVITY = LARTS  SECTION  26  REQUIREMENTS.
CONF= CLU       DF=2  AREA REQ.=   140
   7 DESK          7 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION  29  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   120
   6 DESK          6 CHAIR

 ACTIVITY = LARTS  SECTION  34  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   120
   6 DESK          6 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION  32  REQUIREMENTS.
CONF= RAD       DF=3  AREA REQ.=    18
   3 DESK          3 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION  30  REQUIREMENTS.
CONF= CIR       DF=2  AREA REQ.=    78
   3 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION  31  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=    60
   3 DESK          3 CHAIR
   1 BB

 ACTIVITY = LARTS  SECTION  35  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=    60
   3 DESK          3 CHAIR
   1 BP

 ACTIVITY = LARTS  SECTION  36  REQUIREMENTS.
CONF= F[illegible]   DF=1  AREA REQ.=    60
   1 TABLE         3 CHAIR
   1 BP
```

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```
TIME...11:20

ACTIVITY  SEC.   NO.STD.   AREA REQ.   SPACE   AREA   REQ:USED
 LARTS     27      24        576        C40     391     1.47
 LARTS     33      13        546        C31    1095      .50
 LARTS     28      11        242        C41     204     1.19
 LARTS     26       7        140        C65     142      .99
 LARTS     30       3         78        C33     126      .62
 LARTS     34       6        120        C24     130      .92
 LARTS     29       6        120        0000      0      .00
 LARTS     32       3         18        C44      41      .44
 LARTS     31       3         60        C45      61      .98
 LARTS     36       3         60        C43     109      .55
 LARTS     35       3         60        0000      0      .00
 LARTS     15       7        294        C25     264     1.11
 LARTS     20       7        168        C30     203      .83
 LARTS     23       7        140        C22     144      .97
 LARTS     25      47       1034        C29    1254      .82

AREA REQUIRED     3656 SQ. FT.    AREA  USED    4164 SQ.FT.

 ACTIVITY = SCI     SECTION   5  REQUIREMENTS.
CONF= CIR      DF=1  AREA REQ.=  1856
  10 TABLE        58 CHAIR
   1 BB

 ACTIVITY = SCI     SECTION   3  REQUIREMENTS.
CONF= RAD      DF=2. AREA REQ.=   308
   4 TABLE        22 CHAIR
   1 BB

 ACTIVITY = SCI     SECTION   4  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=   696
   5 TABLE        29 CHAIR
   1 BB

 ACTIVITY = SCI     SECTION   1  REQUIREMENTS.
CONF= CLU      DF=2  AREA REQ.=   576
   5 TABLE        24 CHAIR
   1 MS

 ACTIVITY = SCI     SECTION   2  REQUIREMENTS.
CONF= RAD      DF=3  AREA REQ.=   238
   3 TABLE        17 CHAIR
   1 BB
```

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```
TIME...11:30

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI        5      58        1856     C11   1865   1.00
 SCI        3      22         308     C28    312    .99
 SCI        1      24         576     C46    568   1.01
 SCI        4      29         696     C31   1095    .64
 SCI        2      17         238     C30    203   1.17

AREA REQUIRED    3674 SQ. FT.   AREA  USED     4043 SQ.FT.


TIME...11:40

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI        1      24         576     C46    568   1.01
 SCI        2      17         238     C30    203   1.17
 SCI        3      22         308     C28    312    .99
 SCI        4      29         696     C31   1095    .64
 SCI        5      58        1856     C11   1865   1.00

AREA REQUIRED    3674 SQ. FT.   AREA  USED     4043 SQ.FT.

 ACTIVITY = SCI     SECTION   7  REQUIREMENTS.
CONF= CIR      DF=1  AREA REQ.=    992
   6 TAPLE        31 CHAIR
   1 BB

 ACTIVITY = SCI     SECTION   6  REQUIREMENTS.
CONF= CLU      DF=3  AREA REQ.=    672
   5 TAPLE        28 CHAIR
   1 BB

 ACTIVITY = SCI     SECTION   8  REQUIREMENTS.
CONF= FMI      DF=1  AREA REQ.=    220
   2 TAPLE        11 CHAIR
   6 FP


TIME...11:50

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI        7      31         992     C29   1254    .79
 SCI        6      28         672     C31   1095    .61
 SCI        8      11         220     C30    203   1.08
 SCI        3      22         308     C28    312    .99
 SCI        5      58        1856     C11   1865   1.00

AREA REQUIRED    4048 SQ. FT.   AREA  USED     4729 SQ.FT.
```

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```
TIME...12:00

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
  SCI       3      22        308      C28    312    .99
  SCI       5      58       1856      C11   1865   1.00
  SCI       6      28        672      C31   1095    .61
  SCI       7      31        992      C29   1254    .79
  SCI       8      11        220      C30    203   1.08

AREA REQUIRED    4048 SQ. FT.   AREA  USED    4729 SQ.FT.

ACTIVITY = SCI    SECTION  10  REQUIREMENTS.
CONF= CIR      DF=2  AREA REQ.=  1280
   7 TABLE        40 CHAIR
   1 BB

ACTIVITY = SCI    SECTION  11  REQUIREMENTS.
CONF= FMI      DF=1  AREA REQ.=   160
  16 DESK         16 CHAIR
   1 BB

ACTIVITY = SCI    SECTION   9  REQUIREMENTS.
CONF= CLU      DF=1  AREA REQ.=   120
   1 TABLE         5 CHAIR
   1 BB


TIME...12:10

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
  SCI      10      40       1280      C21   1486    .86
  SCI      11      16        160      C49    159   1.01
  SCI       9       5        120      C22    144    .83
  SCI       5      58       1856      C11   1865   1.00
  SCI       7      31        992      C29   1254    .79

AREA REQUIRED    4408 SQ. FT.   AREA  USED    4908 SQ.FT.

ACTIVITY = SCI    SECTION  12  REQUIREMENTS.
CONF= FMI      DF=2  AREA REQ.=   744
  31 CHAIR
   1 BB
```

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```
TIME...12:20

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI       12      31        744      C29   1254     .59
 SCI        5      58       1856      C11   1865    1.00
 SCI        9       5        120      C22    144     .83
 SCI       10      40       1280      C21   1486     .86
 SCI       11      16        160      C49    159    1.01

AREA REQUIRED   4160 SQ. FT.   AREA  USED    4908 SQ.FT.

 ACTIVITY = SCI     SECTION  14  REQUIREMENTS.
CONF= RAD       DF=1  AREA REQ.=   292
  16 NOFURN
   1 MP             1 HS

 ACTIVITY = SCI     SECTION  15  REQUIREMENTS.
CONF= CLU       DF=2  AREA REQ.=   696
   5 TABLE         29 CHAIR
   1 BB

 ACTIVITY = SCI     SECTION  13  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=   264
   2 TABLE         11 CHAIR
  11 [illegible]

TIME...12:30

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI       14      16        292      C28    312     .94
 SCI       15      29        696      C40    391    1.78
 SCI       13      11        264      C30    203    1.30
 SCI        5      58       1856      C11   1865    1.00
 SCI        9       5        120      C22    144     .83
 SCI       12      31        744      C29   1254     .59

AREA REQUIRED   3972 SQ. FT.   AREA  USED    4169 SQ.FT.

 ACTIVITY = SCI     SECTION  16  REQUIREMENTS.
CONF= CLU       DF=2  AREA REQ.=   672
   5 TABLE         28 CHAIR
   1 BB

 ACTIVITY = SCI     SECTION  19  REQUIREMENTS.
CONF= CLU       DF=2  AREA REQ.=   576
   5 TABLE         24 CHAIR
   1 BB
```

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```
ACTIVITY = SCI     SECTION  19  REQUIREMENTS.
CONF= CIR       DF=1  AREA REQ.=    416
  3 TABLE          13 CHAIR
  1 BB

ACTIVITY = SCI     SECTION  17  REQUIREMENTS.
CONF= CLU       DF=2  AREA REQ.=    220
 11 DESK           11 CHAIR
  1 BB


TIME...12:49

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI       16      28        672      C46    568    1.18
 SCI       19      13        416      C40    391    1.06
 SCI       18      24        576      C31   1075     .53
 SCI       17      11        220      C30    203    1.08
 SCI        5      58       1856      C11   1865    1.00
 SCI       14      16        292      C28    312     .94

AREA REQUIRED    4032 SQ. FT.   AREA  USED    4434 SQ.FT.
 ACTIVITY = SCI     SECTION  20  REQUIREMENTS.
CONF= CLU       DF=1  AREA REQ.=    680
  34 DESK          34 CHAIR
   1 MP             1 BS

 ACTIVITY = SCI     SECTION  21  REQUIREMENTS.
CONF= CIR       DF=1  AREA REQ.=    816
  34 NOFURN
   1 BB

 ACTIVITY = SCI     SECTION  22  REQUIREMENTS.
CONF= CLU       DF=2  AREA REQ.=    144
   2 TABLE          6 CHAIR


TIME...12:50

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI       20      34        680      C26   1230     .55
 SCI       21      34        816      @@@@     0     .00
 SCI       22       6        144      C22    144    1.00
 SCI       16      28        672      C46    568    1.18
 SCI       17      11        220      C30    203    1.08
 SCI       18      24        576      C31   1075     .53
 SCI       19      13        416      C40    391    1.06

AREA REQUIRED    3524 SQ. FT.   AREA  USED    3631 SQ.FT.
```

a school[*] and *appears* to be somewhat larger for open space schools than for traditionally designed schools.

Looking at the summaries for some of the other time steps some further observations can be made. There appears to be adequate space for 150 students at almost every time period. The maximum space required and utilized was at 12:10 when five sections of science required 4408 square feet and used 4883 square feet which represents 69.5% of the 7025 square feet in Pod C. Assuming that the maximum of 30% of the instructional space of the pod has been allocated for circulation and buffer zones--this indicates about the maximum usage of the space. Nevertheless, for the entire day the program only fails to find available space into which to place the schedule activities at 10:40, 11:20, and 12:50. The combination of space used by higher implicit priority activities and previously scheduled activities results in the program's failure to assign a total of five activities to spaces at those times. Although spaces do exist which could have been utilized, the program in its present form does not consider any space whose area is outside the range of 50%-200% of the required area for an activity. In fact some deterioration

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[*] This does not include administrative, maintenance, and toilet facilities.

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TABLE 7-8

TEST RUN 1-DAILY SUMMARY OF SPACE USAGE
TOTAL AVAILABLE MODULES OF TIME-24

I SPACE	MODS IN USE	% MODS USED
C00	0	.00
C10	0	.00
C20	4	.17
C21	2	.08
C22	9	.38
C40	16	.67
C60	0	.00
C61	0	.00
C41	1	.04
C62	6	.25
C63	10	.42
C11	8	.33
C23	5	.21
C24	2	.08
C25	7	.29
C26	1	.04
C42	11	.46
C64	0	.00
C65	2	.08
C80	0	.00
C43	3	.13
C44	4	.17
C45	4	.17
C12	0	.00
C27	1	.04
C28	14	.58
C29	9	.38
C46	14	.58
C66	0	.00
C67	0	.00
C68	0	.00
C47	4	.17
C48	0	.00
C13	1	.04
C30	21	.88
C31	11	.46
C49	2	.08
C50	0	.00
C51	1	.04
C52	1	.04
C32	4	.17
C33	5	.21

does occur in the ratio of space required to space used as the number of activities starting and in process at a particular time gets large--especially when there is a great demand for similarly sized spaces.

After the last of the time step summaries a table (7-8) giving the number and percentage of time modules each space defined in Pod C was used over the whole day. For example, out of 24 available modules of time space C30 was utilized for 21 modules or 88% of the time. The figures in this table must also be interpreted in conjunction with the input floorplan. Clearly space C00 was in constant use (since all the available spaces were subspaces of C00) but it was never specifically assigned to an activity. Some spaces, such as C27 which is a first level subspace of C12 and has no subspaces itself was only used for one ten minute module of time. Its parent space, C12, was not wholly assigned to any activity; therefore C27 could be said to be a lightly used space.

It is evident that a good deal of analysis of space use is possible from the current output of the simulation program. The presentation of Test Run 1 was to provide evidence that the approach taken herein is a viable method for simulating the activities of an elementary school and to introduce the reader to the form and interpretation of the output from the simulation program. The remainder of this section is devoted to the application of the simulation program to specific questions pertaining to the design of a particular school floorplan--namely, the three questions posed in Section 7.2

7.3.3 Example Applications of the Simulation System

In this subsection, the questions proposed in subsection 7.2.2 are addressed. Excerpts from Test Runs 2 and 3 will be displayed as necessary to establish a point, however, the remainder of the output will not be shown.

Question 1--How would School A function if its enrollment were increased by 1/3?

To answer this question, Test Run 2 was made. All inputs and parameters the same as in Test Run 1 with the exception of the ENROLLMENT parameter, which was increased to 200.

The resultant generated schedule of activities (Table 7-9) showed the expected increase in the number of sections of each activity. A consequent increase in the amount of space used and required is also evident. For example at 9:50, thirteen sections of math required 4374 square feet of space and at 12:20, seven sections of science required

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TABLE 7-9

TEST RUN 2

SCHEDULE OF ACTIVITIES

START TIME	END TIME	ACTIVITY	SEC. NO.	NO. STUD.
9:00	10:10	MATH	1	9
9:00	9:10	MATH	2	20
9:00	9:10	MATH	3	18
9:00	9:10	MATH	4	17
9:00	10:10	MATH	5	28
9:00	9:10	MATH	6	93
9:10	9:30	MATH	7	17
9:10	9:40	MATH	8	8
9:10	9:40	MATH	9	3
9:10	9:40	MATH	10	17
9:10	9:40	MATH	11	27
9:10	10:20	MATH	12	25
9:10	9:20	MATH	13	5
9:10	9:40	MATH	14	25
9:10	9:20	MATH	15	23
9:10	9:40	MATH	16	13
9:20	10:30	MATH	17	3
9:20	9:30	MATH	18	17
9:20	9:50	MATH	19	8
9:30	9:40	MATH	20	34
9:40	9:50	MATH	21	27
9:50	10:10	MATH	22	17
9:50	10:30	MATH	23	35
9:50	10:30	MATH	24	8
9:50	10:30	MATH	25	16
9:50	10:00	MATH	26	17
9:50	10:10	MATH	27	3
9:50	10:00	MATH	28	5
9:50	10:30	MATH	29	30
9:50	10:00	MATH	30	4
10:00	10:10	MATH	31	3
10:00	10:30	MATH	32	20
10:00	10:30	MATH	33	3
10:10	10:20	MATH	34	25
10:10	10:30	MATH	35	35
10:20	10:30	MATH	36	50
10:30	10:50	LARTS	1	3
10:30	10:50	LARTS	2	5
10:30	10:40	LARTS	3	15
10:30	11:00	LARTS	4	18
10:30	11:10	LARTS	5	16
10:30	10:40	LARTS	6	7

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10:30	10:50	LARTS	7	6
10:30	10:50	LARTS	8	7
10:30	10:50	LARTS	9	8
10:30	10:40	LARTS	10	8
10:30	11:00	LARTS	11	9
10:30	11:30	LARTS	12	7
10:30	10:40	LARTS	13	9
10:30	10:50	LARTS	14	7
10:30	11:00	LARTS	15	34
10:30	10:50	LARTS	16	6
10:30	11:10	LARTS	17	7
10:30	10:50	LARTS	18	9
10:30	10:50	LARTS	19	17
10:40	11:10	LARTS	20	7
10:40	10:50	LARTS	21	6
10:40	11:00	LARTS	22	26
10:50	11:10	LARTS	23	7
10:50	11:00	LARTS	24	24
10:50	11:00	LARTS	25	11
10:50	11:30	LARTS	26	6
10:50	11:10	LARTS	27	3
10:50	11:30	LARTS	28	3
10:50	11:00	LARTS	29	3
10:50	11:00	LARTS	30	13
10:50	11:20	LARTS	31	6
11:00	11:10	LARTS	32	3
11:00	11:30	LARTS	33	10
11:00	11:30	LARTS	34	7
11:00	11:30	LARTS	35	6
11:00	11:30	LARTS	36	6
11:00	11:30	LARTS	37	29
11:00	11:30	LARTS	38	26
11:00	11:20	LARTS	39	28
11:00	11:30	LARTS	40	23
11:10	11:30	LARTS	41	11
11:10	11:30	LARTS	42	5
11:10	11:30	LARTS	43	27
11:20	11:30	LARTS	44	3
11:20	11:30	LARTS	45	13
11:20	11:30	LARTS	46	5
11:20	11:30	LARTS	47	5
11:20	11:30	LARTS	48	8
11:30	11:50	SCI	1	28
11:30	11:50	SCI	2	11
11:30	11:50	SCI	3	24
11:30	11:40	SCI	4	20
11:30	11:40	SCI	5	34
11:30	11:50	SCI	6	34
11:30	11:50	SCI	7	30
11:30	12:00	SCI	8	17
11:40	11:50	SCI	9	3
11:40	12:10	SCI	10	32

```
11:40          12:10          SCI            11          19
11:50          12:00          SCI            12          17
11:50          12:10          SCI            13           7
11:50          12:20          SCI            14         109
12:00          12:30          SCI            15          27
12:00          13:00          SCI            16          11
12:10          12:20          SCI            17          26
12:10          12:40          SCI            18          18
12:10          12:30          SCI            19          12
12:10          12:20          SCI            20           2
12:20          12:30          SCI            21          30
12:20          12:40          SCI            22          35
12:20          12:40          SCI            23          13
12:20          12:30          SCI            24          54
12:30          13:00          SCI            25          64
12:30          12:50          SCI            26          26
12:30          13:00          SCI            27          17
12:30          13:00          SCI            28          16
12:40          13:00          SCI            29          35
12:40          13:00          SCI            30          17
12:40          13:00          SCI            31          14
12:50          13:00          SCI            32          17
12:50          13:00          SCI            33           9
```

4384 square feet (Table 7-10). Still, assignments took place at these times for all but one of the activities scheduled.

At the start of the Language Arts block (10:30), 19 sections are scheduled, twelve of which require between 100 and 260 square feet of space. Combined with the demand put on space by higher priority activities, this requirement results in three sections not being assigned. Again, it should be noted that there still existed spaces available but they were not considered suitable by the program under its present constraints on the range of areas for the selection of alternative spaces. For the day, out of 117 scheduled sections of activities only thirteen were not assigned spaces.

The summary of modules in use per space (Table 7-11) shows a general increase in usage both in the number of spaces which were put into use as well as the number of modules that were occupied. However, many of the spaces were used less than 60% of the time available--some of these, of course, were not available when their parent spaces or subspaces were occupied. The conclusion which can be drawn from this run would indicate that there is adequate space for 200 students in Pod C00 of School A if optimal spatial configurations are observed.

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TABLE 7-10

TEST RUN 2
SELECTED ACTIVITY ASSIGNMENT SUMMARIES

TIME... 9:50

ACTIVITY	SEC.	NO.STUD.	AREA REQ.	SPACE	AREA	REQ:USED
MATH	29	30	720	C31	1095	.66
MATH	23	35	1120	C26	1230	.91
MATH	25	16	256	C47	251	1.02
MATH	30	4	60	C33	126	.63
MATH	28	5	120	C24	130	.92
MATH	22	17	102	0083	0	.00
MATH	24	8	160	C62	164	.98
MATH	26	17	408	C28	312	1.31
MATH	27	3	72	C22	144	.50
MATH	1	9	216	C30	203	1.06
MATH	5	28	560	C40	391	1.43
MATH	12	25	500	C46	568	.88
MATH	17	3	60	C63	52	1.15

AREA REQUIRED 4374 SQ. FT. AREA USED 4666 SQ.FT.

TIME...12:00

ACTIVITY	SEC.	NO.STUD.	AREA REQ.	SPACE	AREA	REQ:USED
SCI	15	27	648	C40	391	1.66
SCI	16	11	264	C47	251	1.05
SCI	10	32	768	C46	568	1.35
SCI	11	19	456	C42	344	1.33
SCI	13	7	168	C62	164	1.02
SCI	14	104	2080	C13	1758	1.18

AREA REQUIRED 4384 SQ. FT. AREA USED 3476 SQ.FT.

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```
TIME...10:30

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 LARTS     15     34        884       C29   1254     .70
 LARTS      5     16        320       C28    312    1.03
 LARTS     19     17        340       C42    344     .99
 LARTS      4     18        360       C40    391     .92
 LARTS      8      9        216       C30    203    1.06
 LARTS     12      7        224       C20    232     .97
 LARTS      7      6        144       C22    144    1.00
 LARTS     14      7        154       C27    165     .93
 LARTS     17      7        154       C62    164     .94
 LARTS     11      9        198       C32    201     .99
 LARTS     18      9        378       @@@@     0     .00
 LARTS      9      8         80       C45     61    1.31
 LARTS      3     15        240       C23    235    1.02
 LARTS     16      6        252       C25    264     .95
 LARTS      2      5        210       @@@@     0     .00
 LARTS     13      9        198       @@@@     0     .00
 LARTS     10      8        128       C43    109    1.17
 LARTS      6      7        154       C24    130    1.18
 LARTS      1      3         48       C63     52     .92

AREA REQUIRED   4682 SQ. FT.   AREA USED   4261 SQ.FT.
```

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TABLE 7-11

TEST RUN 2-DAILY SUMMARY OF SPACE USAGE
TOTAL AVAILABLE MODULES OF TIME-24

I SPACE	MODS IN USE	% MODS USED
C00	0	.00
C10	0	.00
C20	6	.25
C21	3	.13
C22	11	.46
C40	20	.83
C60	0	.00
C61	0	.00
C41	0	.00
C62	15	.63
C63	14	.58
C11	2	.08
C23	4	.17
C24	6	.25
C25	8	.33
C26	6	.25
C42	14	.58
C64	1	.04
C65	2	.08
C80	0	.00
C43	2	.08
C44	1	.04
C45	5	.21
C12	0	.00
C27	7	.29
C28	20	.83
C29	3	.13
C46	18	.75
C66	0	.00
C67	0	.00
C68	3	.13
C47	13	.54
C48	1	.04
C13	3	.13
C30	18	.75
C31	17	.71
C49	0	.00
C50	0	.00
C51	0	.00
C52	0	.00
C32	7	.29
C33	10	.42

Question 2--If certain spaces are seen to be underused, how would their removal affect the ability of School A to provide space for activities?

This question is relatively easy to answer with the simulation program. In Test Run 1 (refer to Table 7-7) for example, it was pointed out that space C27 was used for only one ten minute module of time--for Language Arts Section 13 at 10:40. Using the detailed listing option,* the spaces considered for this activity and their scores were listed (Table 7-12). C62, the best suited space was assigned to Section 14. Spaces C27, C22, and C65 were still available however, and were roughly equivalent in score for this activity. If C27 had been eliminated from the floorplan, the activity would have been assigned to space C22 or C65 and no other noticeable difference in the functioning of the school would have been evident.

This information was deduced from the results of a run in the detailed mode. The space C27 simply could have been eliminated from the input space list and the simulation program run without it to obtain the same information directly. Experimentation could also be performed by removing combinations of questionable spaces to yield space

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*The detailed listing prints the list of alternative spaces for each activity along with their scores.

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TABLE 7-12

POTENTIAL SPACE SCORES FOR LARTS SECTION 13

```
  ACTIVITY = LARTS  SECTION  13  REQUIREMENTS.
 CONF= CLU        DF=1  AREA REQ.=   160
    8 DESK          8 CHAIR
    1 BB
ACTIVITY  LARTS  SECTION  13
SPACE = C62     SCORE =    197.50
SPACE = C27     SCORE =    196.87
SPACE = C22     SCORE =    190.00
SPACE = C65     SCORE =    163.75
SPACE = C50     SCORE =    -13.12
SPACE = C49     SCORE =    -13.12
SPACE = C61     SCORE =    -60.62
```

use figures on any subset of the original set of spaces on the floorplan. In any case, it is obvious that with an enrollment of 150 students in Pod C space C27 could be considered superfluous.

Question 3--What would result if the model for School A were used in a simulation on the floorplan of School B?

Test Run 3 which ran the multiunit methodology against the floorplan of School B was designed to answer this question. All parameters and inputs were the same as for Test Run 1 except , of course, the floorplan; thus the schedule and required space for each time period were the same in both cases.

In the floorplan for School B, Area A, roughly the equivalent of Pod C of School A, contains approximately 4220 square feet of space. This space was partitioned with room dividers into five homeroom areas, each seating around 30 students. Therefore, neither space A00 as a whole nor any of the five homeroom areas (the largest of which was 794 square feet) could accommodate the full 150 student enrollment as a single group.

The five homeroom areas shown in Figure 7-2 house a large number of subspaces. Although these represent areas in which students were observed to work as a group, it was not usually the case that all the subdivisions of a space were observed simultaneously housing separate groups of students. This is because there was no real separation or buffer areas between one subspace and another in most of the homeroom areas. Nevertheless, to the simulation program, all the defined subspaces were considered as available spaces for the assignment of activities--thus it would be expected that for activities not requiring more than 1588 square feet of space (which would allow the 794 square foot space to be considered), the simulation program would be likely to find space for most or all of the activities scheduled at a given time. However, at those times (see Test Run 1) when the scheduled activities require more than 3500 square feet of space any assignment at all would be a tight fit at best.

These observations are borne out by the excerpts from a simulation test run shown in Table 7-13. In the optimal mode only one section of Math was not assigned to a space (see time 9:10), and the homogeneity of requirements for space resulted in some assignments which placed activities into substantially smaller or larger spaces than they required. This is in evidence from the spaces required to space used ratio computed for activities scheduled at 9:50, 10:10, and 12:20.

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TABLE 7-13

TEST RUN 3
SELECTED ACTIVITY ASSIGNMENT SUMMARIES

TIME... 9:10

ACTIVITY	SEC.	NO.STUD.	AREA REQ.	SPACE	AREA	REQ:USED
MATH	12	25	500	A01	309	1.62
MATH	11	27	648	A05	565	1.15
MATH	10	17	340	A27	279	1.22
MATH	7	17	340	A17	269	1.26
MATH	14	11	220	A22	190	1.16
MATH	8	8	160	A18	173	.92
MATH	2	3	60	A66	66	.91
MATH	13	5	100	GROW	0	.00
MATH	1	9	216	A15	217	1.00
MATH	5	20	448	A06	493	.91

AREA REQUIRED 3032 SQ. FT. AREA USED 2561 SQ.FT.

TIME... 9:50

ACTIVITY	SEC.	NO.STUD.	AREA REQ.	SPACE	AREA	REQ:USED
MATH	20	17	408	A26	273	1.49
MATH	1	9	216	A15	217	1.00
MATH	5	20	448	A06	493	.91
MATH	12	25	500	A01	309	1.62
MATH	16	22	220	A24	218	1.01
MATH	17	3	60	A79	62	.97
MATH	19	46	460	A03	794	.58

AREA REQUIRED 2312 SQ. FT. AREA USED 2367 SQ.FT.

TIME...10:10

ACTIVITY	SEC.	NO.STUD.	AREA REQ.	SPACE	AREA	REQ:USED
MATH	23	35	700	A02	785	.89
MATH	29	21	336	A26	273	1.23
MATH	26	17	340	A07	242	1.40
MATH	22	17	340	A84	660	.51
MATH	25	16	384	A03	794	.48
MATH	24	8	192	A18	173	1.11
MATH	27	3	126	A29	141	.89
MATH	28	5	80	A31	92	.87
MATH	12	25	500	A01	309	1.62
MATH	17	3	60	A79	62	.97

AREA REQUIRED 3058 SQ. FT. AREA USED 3542 SQ.FT.

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```
TIME...10:30

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 LARTS      2      125       2750     @@@@     0     .00
 LARTS      1       25        500     A02    786     .63

AREA REQUIRED   3250 SQ. FT.   AREA  USED      786 SQ.FT.

TIME...12:20

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 SCI       12       31        744     A02    786     .94
 SCI        5       58       1856     @@@@     0     .00
 SCI        9        5        120     A30    104    1.15
 SCI       10       40       1280     A03    795    1.61
 SCI       11       16        160     A25    172     .93

AREA REQUIRED   2362 SQ. FT.   AREA  USED     1858 SQ.FT.
```

From the daily summary of space use, it can be seen that four of the main homeroom areas A01, A02, A03, and A05 were the most heavily used, despite the abundance of smaller subspaces. This could be an indication of the need for more similarly sized spaces.

Science Section 5 at 12:20 which involved 58 students requiring 1856 feet was not assigned a space, as expected; neither was a Language Arts Section (2) in which 125 students required 2750 square feet.

In eleven out of the 25 modules of time steps there were requirements for between 3600 and 4200 square feet of space, leaving less than 15% of the entire area for circulation--and this does not take into consideration the space taken up by the partitions dividing the area.

Two conclusions can be drawn from the results of simulating the multiunit methodology on the floorplan of School B. First, the lack of adequate large spaces is a handicap to the large group instructional mode employed in the multiunit school. The simulation generates large group activities with their associated large space requirements, but finds no suitable space in which they may be conducted. Second, the large number of observed subdivisions of the floorplan for Area A allowed the assign-

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TABLE 7-14

TEST RUN 3-DAILY SUMMARY OF SPACE USAGE
TOTAL AVAILABLE MODULES OF TIME-24

```
1 SPACE   MODS IN USE   % MODS USED


    A00             0           .00
    A01            20           .83
    A10             0           .00
    A11             0           .00
    A12             0           .00
    A13             0           .00
    A02            13           .54
    A14             2           .08
    A40             0           .00
    B40             0           .00
    B41             0           .00
    A15             9           .38
    A41             0           .00
    A16             0           .00
    A42             0           .00
    A43             0           .00
    A17             4           .17
    A44             0           .00
    A45             0           .00
    A03            11           .46
    A18             7           .29
    A46             0           .00
    A47             0           .00
    A48             0           .00
    A49             0           .00
    A19             2           .08
    A50             0           .00
    A51             0           .00
    A52             0           .00
    A53             0           .00
    A20             3           .13
    A54             0           .00
    A55             0           .00
    A56             0           .00
    A57             0           .00
    A21             0           .00
    A58             2           .08
    A59             0           .00
    A60             0           .00
    A61             0           .00
    A04             2           .08
    A22             9           .38
```

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A62	0	.00
A63	0	.00
A64	0	.00
A95	0	.00
A65	0	.00
A23	4	.17
A66	7	.29
A96	0	.00
A67	1	.04
A68	0	.00
A69	0	.00
A24	5	.21
A70	0	.00
A71	1	.04
A72	0	.00
A73	0	.00
A25	4	.17
A74	0	.00
A75	1	.04
A05	12	.50
A26	5	.21
A76	0	.00
A77	0	.00
A78	0	.00
A27	8	.33
A79	5	.21
A97	0	.00
A80	0	.00
A81	0	.00
A98	0	.00
A99	0	.00
A82	1	.04
A06	7	.29
A28	2	.08
A83	0	.00
A84	8	.33
A85	2	.08
A29	3	.13
A86	0	.00
A30	8	.33
A87	0	.00
A88	0	.00
A31	3	.13
A89	1	.04
A90	0	.00
A07	2	.08
A32	0	.00
A33	0	.00
A34	0	.00
A35	0	.00

ment algorithm to find space for almost all of the activities scheduled; however, as was noted, there was very little space left over for circulation or buffer areas between activities.

7.4 Discussion

What has been shown in this chapter is that the simulation system designed for aiding in the design and evaluation of school floorplans can indeed by a useful tool for the school architect. Utilizing a prototype program (which does not include all of the design features) and a basic set of output data, the system successfully simulated an observed multiunit school on its own floorplan and then was used to provide information about the functionality of the floorplan under altered conditions. The program was further used to analyze the design of a floorplan for a school operating under a traditional methodology to determine how it would function under the multiunit program. These were representative of the kinds of tests for which the system was designed.

Much of the success of the program is related to the accuracy of the observers and their ability to identify and record the details of the spatial environment being observed. For example, it was not until observing in School A (which was observed last) that the ability of the observers to provide accurate floorplans was well established. It is probable that the subdivisions of School B (the first observed school) were not entirely precise. Nevertheless, the analysis of question 3

(Section 7.3.3) was made assuming that the given floorplan was a correct one. The program was still able to establish some of the differences of the architectural demands of the multiunit program as opposed to a traditional program.

As was mentioned previously, only basic outputs were supplied by the prototype system. Although these were sufficient to allow the computation of averages or tabulation of certain kinds of space use figures, it would not be hard to expand the output to include these features at the user's option. All of the information in the activity control block is available to the system at all times, thus allowing a good deal of flexibility in the design of the specific output for a particular user.

In terms of the actual use of space by one school program versus another it is worth mentioning that if 150 students were divided into five 30 student groups and assigned to a single 750 square foot area (25 square feet per student) and if traditional scheduling were employed[1] much less space would be required (3750 square feet in this example) for instructional activities than appears to be necessary as the groupings and scheduling become more complex. It is this very complexity, however, which is seen as a major rationale for the development of the system described in this thesis.

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[1] All activities start or end at the same time--activities always involve whole group of 30 students.

CHAPTER 8

Implications for Future Research and Summary

8.1 Introduction

The system described in this thesis represents only an initial step into what is envisioned as an important new application area for computers. Within the scope of the present system there exist several areas for further research and/or development. These can be divided into three categories: 1) improvements and additions to the program itself, 2) implementation of the program in an interactive mode, and 3) establishment of a permanent data base.

In the remaining sections of this chapter, these areas for future research will be discussed. The last section will provide a short summary for the thesis.

8.2 Implications for Future Research

8.2.1 Improvements and Additions to the Simulation Program

The major area of research for improving the simulation program lies in the modifications of the assignment algorithm.

The method of assignment of activities to spaces can be modified in at least two ways which would broaden the scope of the simulation program. The first would be to allow the program to build spaces out of existing, unoccupied subspaces when appropriate. The second would allow just the opposite--the subdivision of spaces into smaller spaces when necessary. Such capabilities would give the designer a greater degree of flexibility than he now has to specify instructional areas on his design. It would even be possible to direct the program to select from a totally undivided space those areas which would seem appropriate for certain activities. For this particular application, however, it would be necessary to derive methods similar to those employed in the solution of wiring layout problems to deal with the relationship of activities to one another and the subsequent placement of those activities. Only the relations between activities and permanent resources (if any) would be considered by the assignment algorithm in the placement of activities.

The tree structured floorplan representation is quite suitable for the implementation of algorithms which would divide or coalesce spaces. All that is required is the insertion or removal of appropriate nodes representing the desired configuration of a space. Because of the four way linkage between one node and another in the tree, the addition or deletion of any node can be made directly without the necessity of traversing the tree to that node just to maintain appropriate pointers (as would be the case in a one way linked list). In fact, the service routines for adding or deleting a node anywhere in the tree already exist as a part of the tree building program.

One further improvement to the assignment process would be the addition of a lookahead procedure. What this would mean is that for each time step the program would make a set of tentative assignments instead of just one. Furthermore, it would iterate through several (usually some arbitrarily defined number) time steps repeating the same process for each of the alternatives at that time step. At some point the program could determine whether an earlier assignment had seriously interfered with the placement of a later activity and make decisions on the locations of activities given the new source of information. This addition would be justified if more of an emphasis were placed on an optimum assignment of activities than is currently the case.

8.2.2 Implementation of an Interactive Capacility for the Simulation

Operating essentially in a batch mode as it currently does, the simulation program presents several handicaps to a potential user. For example, the method of preparing input floorplans and the associated hierarchical list of spaces is cumbersome. Experimentation with the floorplan or the modification of parameters is limited; and of course, the user must be prepared to wait for his output.

Perhaps the highest priority item which should be given an interactive capability is the input floorplan. Any CRT with a vector generating feature and an external input device such as a light pen would allow the architect to draw a floorplan and specify spaces and subspaces on the plan with a minimum of effort. Using existing algorithms the program can build the hierarchy of spaces thus alleviating the designer from the tedious preparation of the hierarchial space list.* The specification of resources would also be simplified. Upon the designation of a space an enlargement of that area could be presented to the user and he could then enter resources via a keyboard. A more sophisticated procedure would allow the specification of resources and their location in the space right into the floorplan as shown on the screen.

---

*The author has programmed an overlapping polygon detection procedure which can determine whether a region defined by its coordinates or any part of it is contained by another region.

Additional features which could be provided interactively are the specification of individual students whose progression through the schedule could be monitored and the manipulation of the coefficients for the scoring polynomial in the assignment algorithm. For the former case a structure already exists in the Activity Control Block whereby the individual students assigned to a section of an activity is recorded and maintained. Such a feature would be able to provide information on circulation of students within the designed spaces. In the latter case, the capability would have to be added to the program, but would provide yet another level of flexibility to the designer who may wish to emphasize the importance of certain resources to an activity and determine their effect upon the assignment of activities to spaces.

8.2.3 Establishment of a Permanent Data Base

For the simulation program to be effective its data base must be reliable. A large scale data collection procedure would have to be undertaken to provide the system with such a base. An appropriate sample of schools would be selected; the range of observed activities would be expanded to include specialized instructional activities such as music, physical education, workshop, and laboratories. Activities would be observed an appropriate number of times to provide a statistically reliable sample from which to draw inferences for the school program being modeled.

8.4 Summary

This thesis has presented a system for the computer aided design and evaluation of elementary school floorplans. The system consists of 1) an observation phase for providing data from which to build models of elementary school activities under specific educational programs and 2) a computer program which applies the model to a proposed floorplan by generating a schedule of activities and their requirements, their steps through the schedule, and attempts to make an assignment of activities to spaces available at each time step.

The output from the program, in the form of space usage summaries at each time step and at the end of the scheduled day, has been shown to be of value in assessing how the designed space fits the needs of a school program and how flexible the floorplan is with respect to changing enrollments.

No attempt was made to program a full scale production system. Rather, the intent was to provide the basis for the implementation of such a system and to provide evidence for the justification and viability of pursuing this research. On the basis of the results of the observation procedure and experiments with a prototype system it is felt that the continuance of research into the problem areas identified in this research are indeed warranted.

APPENDIX A

Development of an Observer Recording Sheet

DEVELOPMENT OF AN OBSERVER RECORDING SHEET

Two different kinds of recording methods were tested before the final procedure was adopted. First, a narrative type recording sheet was developed. The observer was expected to record in narrative form all of the events he saw taking place in the space. The observer was given a floorplan for his space, a sheet of observation procedures (page 256) and several observation forms (page 257). For each event that occurred the observer would note the time and write a description of what he saw.

A test of narrative-type observation sheet was made at an open-plan school with three volunteer observers. Results were similar to those shown on page 258. Translation of the recorded data to a format which could be keypunched and read by a computer was quite difficult because of the volume and ambiguity of the recording.

A second observation sheet was designed on which an entire event could be described on one line. Descriptors were assigned to specific columns on the sheet and consisted of quantitative and categorical items. The start time of each activity was recorded and activities were codified and broken down into three phases--onset, instructional, and code. (See pages 259-261.)

A field test of the revised form revealed several inadequacies. Because only the start time of an event was being recorded, it was difficult to compute its duration. (An activity was assumed to have terminated when a new one started in the same location.) The phases of an activity were often indiscernible or too brief to be of note.

Revisions made to the observation form included adding a column for the end time of an activity, and dropping the phase codes of activities. The final version of the form is described in Appendix B.

OBSERVATION PROCEDURES

1. Fill in heading information on observer sheet.

2. Write items and numbers of pieces of equipment in the area to be observed in margin at left of sheet.

3. As an event occurs, record the starting time and begin the detailed commentary of what is taking place. Use location codes as indicated on the floor plan. Essentially, an event is a change in status of something in the observed space. This can mean things like a change in the activity or subject being pursued, the entrance and exiting of groups or individuals, a change in the physical configuration in the room etc. Any change of status in any of the following items can be considered to be an event. Pay close attention to them and record their status frequently.

   - Subject being studied
   - Groups and size of groups (if a group divides, give the new groups names like G1, G2 etc. and record their activities
   - Number and types of supervisory personnel
   - Center of attention of the group (e.g. teacher, device, etc.)
   - Equipment in use
   - Physical configuration of people and equipment in the space
   - Noise level
   - Level of physical activity

4. Feel free to make evaluations, but enclose all evaluations in brackets [--]. Try to make the evaluations reflect architecturally significant observations such as: "activity needs more space" or "lighting is inadequate".

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Observation	Location B
School	
Date	

List of Equipment		Time	Description of Events
Item	Total		

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Observer	Location B
School	
Date	

List of Equipment		Time	Description of Events
Item	Total	9:00	32 S enter space, Noise High, sit at desks, frontal
DEsks CHairs Tables Teach Desk	42 55 2 1	9:04	T walks in hands out exercise sheets. (Kids pull out stationery from desks) desks arranged in rows, 6 rows 7 desks each facing Black Boards (see plan)
Bookcase H	3	9:06	Quiz begins, Noise Low, Subject--Math
Bookcase L	2	9:18	Quiz ends--sheets handed in.
Black Board SCreen TV Movie Projec	2 1	9:21	Projector brought in, chairs moved to Location B_2, facing screen hanging from BB2. |small children have trouble moving chairs| 9 S and 1 T join the group, shades pulled over windows, lights out.
COnstruction		9:31	Movie starts--subject social studies
Tools		9:51	Movie ends, lights on.
		9:56	Discussion starts--(social studies) seating arrangement--no change.
		10:04	Change configuration into groups 5 and 6 each (G2-G6) 1 of 5 (G7) 6 S & 1 T leave the space.
		10:06	individual work starts: 1 group works with teacher on math problems around table location B_3 3 Groups work at desks on math, noise level medium. 1 Group playing game on floor near BB1. 1 Group of 5 building hut location B_4. [groups working well, group building hut disturbs G2]
		10:21	Another teacher enters works with group at B_1 on math.
		10:25	First teacher stops with group, supervises 3 groups at desks plus original group.

KEY TO RECORDING SHEET

1. Time - start time of an event.

2. Activity phase - the activity observed can be said to have distinct phases, the onset, the instructional or main phase and the code, or end. Within each phase the activity is further broken down as shown in Figure 1.

3. Group size - number of pupils in group being observed.

4. Location - name assigned to a location as described on observer's floor plan.

5. Subject - a 3 or 4 letter code naming the subject to be studied.

6. Supervision - number and type of supervisory personnel (teachers, aides, etc.).

7. Attention - a code describing the group's focus of attention.

8. Configuration - a code describing the physical configuration of

9. Equipment in use - a list of codes describing each piece of equipment in the room which is actively in use.

10. Noise - an estimate of the level of noise being generated by the group being observed (Low(L), Medium(M), High(H)).

11. Physical activity - an estimate of the level of physical activity of the group being observed (Low(L), Medium(M), High(H)).

12. Comments - appropriate comments by the observer. Such comments should be of the form: "Too much space", "too little space", "interference from noise", "lighting adequate", etc.

ACTIVITY PHASES AND CODES

I. Onset

OW - Students walk into space
OF - Movement of furniture
OM - Exchange of materials (turning in papers, passing out equipment, etc.)
OE - Setting up equipment
OO - Organizational activity
OC - Change of configuration
ON - No movement of people or equipment

II. Instructional or main

IL - Lecture
ID - Demonstration
IQ - Question and answer session
IS - Individual student presentation
IC - Class discussion
II - Independent work
IG - Group work
IT - Test
IM - Movie
IP - Playing

III. Coda

CW - Students walk out of space
CF - Movement of furniture
CM - Exchange of materials
CE - Removal of equipment
CT - Transitional event (people moving in and out of room)

SAMPLE RECORDING SHEET

OBSERVER

SCHOOL TYPE

SPACE LOCATION

SCHOOL

DATE

Time	Activity Phase	Group Name	Group Size	Loc.	Subj.	Supervision	Attention	Configuration	Equipment in Use	Noise	Phys. Activ.	Comments

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APPENDIX B

Final Version of the Observer Recording Sheet and Instructions to Observers

279

Observer: ____________ School: ____________

Page ____ Date: ____________ Space: ____________

	TIME														OTHER EQUIPMENT							
LINE	START	END	LOC	GRP	ST	#S	#T	EVENT	BASIC CONFIG	DF	#CH	#DE	#TA	#TD								
01																						
02																						
03																						
04																						
05																						
06																						
07																						
08																						
09																						
10																						
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21																						
22																						
23																						
24																						
25																						

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RECORDING SHEET INSTRUCTIONS

1. PAGE - Letter the pages consecutively starting with "A".

2. LINE - The line number is filled in.

3. TIME - Record the time of day running from 0000 (12:00 midnight) to 2400 (11:00 PM) as each event starts and ends.

4. LOC - Name of the subspace being observed consisting of the letter name assigned to the main space (Space blank in recording sheet heading) and a two digit number from 01 to 99.

5. GRP - Name of the group being observed consisting of a letter (preferably "G") and a two digit number from 01 to 99.

6. GT - Group Type. If the people in the group are ding individual work record "I". If they are acting as a group, record a "G".

7. #S, #T - Record the number of students and teaching personnel, respectively.

8. EVENT - See EVENT CODES

9. BASIC CONFIG. - See CONFIGURATION CODES

10. DF - Distraction Factor. An estimate of how much this activity would affect other activities occurring immediately adjacent to it without separating materials. Record a "1" for no distraction, "2" for little distraction, "3" for moderate distraction, and "4" for high distraction.

11. #CH, #DE, #TA, #TD - Record the number of CHairs, DEsks, TAbles, and Teacher's Desks respectively.

12. Other equipment - See accompanying list.

13. The last column under OTHER EQUIPMENT will be used as follows: If an asterisk is placed rightmost in the column, all the information on the line will be considered as commentary. Feel free to comment often and on any subject but with special emphasis on the use of space.

    If a page letter and line number appear left-adjusted in the column, the line will be assumed to be a continuation of the line designated.

EVENT CODES

I. Subject Events

A. Language arts

1. Communicative activities	COMM
2. Listening	LISTEN
3. Speech	SPCH
4. Reading	READ
5. Writing	WRITE
6. Spelling	SPELL
7. Grammar	GRMR

B. Mathematics

1. Addition	ADD
2. Subtraction	SUB
3. Multiplication	MULT
4. Division	DIV
5. Set theory	SETS

C. Social studies

1. Current events	CURR
2. Geography	GEOG
3. History	HIST
4. Political science	POL

D. Science

1. Physical science	PHYSCI
2. Biology	BIOL
3. Experiments	EXPER
4. Process activities	PROC*

E. Art

1. Drawing, painting, etc.	DRAW
2. Construction	CONST
3. Art appreciation	ARTA
4. Art history	ARTH

F. Music

1. Playing instruments	PLAYIN
2. Singing	SING
3. Dancing	DANCE
4. Music appreciation	MUSA
5. Music theory	MUST
6. Music history	MUSH

---

*Process activities include inquiry, observation, and classification.

EVENT CODES (Continued)

G. Other events

1.	Increase in group size	INC
2.	Decrease in group size	DEC
3.	Break into smaller groups	BRK
4.	Combine groups	COMB
5.	Change of group type	CHTYP
6.	Arrange equipment	ARREQ
7.	Circulation within space	CIRCI
8.	Circulation in and out of space	CIRCW
9.	Recess	RECESS
10.	General homeroom activities	GEN
11.	Space unused	EMPTY

CONFIGURATION CODES[**]

I. Basic configurations

- A. Rectangular
  1. Frontal minimal with desks .... FMIND
  2. Frontal optimal with desks .... FOPTD
  3. Frontal minimal with tables .... FMINT
  4. Frontal optimal with tables .... FOPTT
  5. Frontal minimal with chairs .... FMINC
  6. Frontal optimal with chairs .... FOPTC
  7. Frontal minimal - no furniture .... FMIN.
  8. Frontal optimal - no furniture .... FOPT.
- B. Circular
  1. Circular with desks .... CIRCD
  2. Circular with tables .... CIRCT
  3. Circular with chairs .... CIRCC
  4. Circular without furniture .... CIRC.
- C. Radial
  1. Radial with desks .... RADD
  2. Radial with tables .... RADT
  3. Radial with chairs .... RADC
  4. Radial without furniture .... RAD.
- D. Clustered
  1. Clustered with desks .... CLUDn[*]
  2. Clustered with tables .... CLUTn
  3. Clustered with chairs .... CLUCn
  4. Clustered without furniture .... CLU-n

---

[*] Record the average number of items in the cluster for "n". Items means furniture in 1, 2, and 3, and students in 4.

[**] Configurations should be recorded as one of the codes above followed by a space density indicator. The space density indicators are:

1. Sparse ..... S
2. Moderate ... M
3. Heavy ...... H

CONFIGURATION CODES[*]

I. Basic configurations

A. Rectangular
  1. Frontal minimal with desks .... FMIND
  2. Frontal optimal with desks .... FOPTD
  3. Frontal minimal with tables .... FMINT
  4. Frontal optimal with tables .... FOPTT
  5. Frontal minimal with chairs .... FMINC
  6. Frontal optimal with chairs .... FOPTC
  7. Frontal minimal - no furniture .... FMIN.
  8. Frontal optimal - no furniture .... FOPT.

B. Circular
  1. Circular with desks .... CIRCD
  2. Circular with tables .... CIRCT
  3. Circular with chairs .... CIRCC
  4. Circular without furniture .... CIRC.

C. Radial
  1. Radial with desks .... RADD
  2. Radial with tables .... RADT
  3. Radial with chairs .... RADC
  4. Radial without furniture .... RAD.

D. Clustered
  1. Clustered with desks .... CLUDn[*]
  2. Clustered with tables .... CLUTn
  3. Clustered with chairs .... CLUCn
  4. Clustered without furniture .... CLU-n

---

[*] Configurations should be recorded as one of the codes above followed by a space density indicator. The space density indicators are:

  1. Sparse ...... S
  2. Moderate..... M
  3. Heavy........ H

[**] Record the average number of items in the cluster for "n". Items means furniture in 1, 2, and 3, and students in 4.

OTHER EQUIPMENT

Equipment should be recorded as a two digit number from 01 to 99 followed by a two character equipment code. Record only the equipment used actively by the people in the subspace.

I. Equipment codes

A.	Blackboard (permanent)	BB
B.	Blackboard (portable)	BP
C.	Partitions	PA
D.	Carrels	CA
E.	Television set	TV
F.	Television stand	TS
G.	Radio	RA
H.	Record player	RP
I.	Movie projector	MP
J.	Movie screen	MS
K.	Film strip projector	FP
L.	Tape recorder	TR

If there is not enough space to record all of the equipment used in an activity, use additional lines on the recording sheet. Record the additional equipment under the OTHER EQUIPMENT columns except for the last column on the page. Write the page letter and line number (left-adjusted) for which the current line is a continuation in this column.

APPENDIX C

The Computation of Floor Space in Subroutine PAREA

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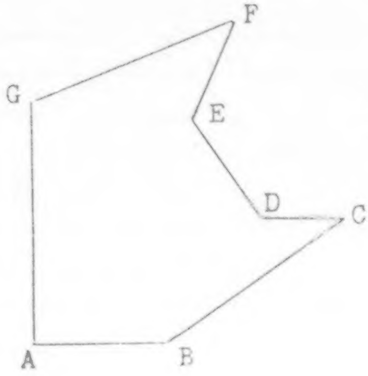
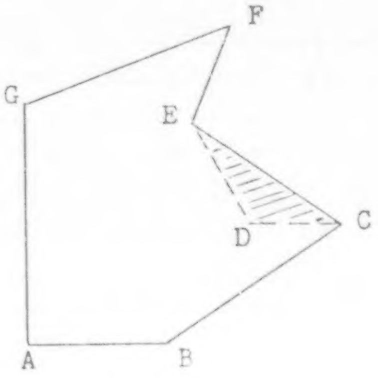
The computation of school floor space is made in the program PAREA. PAREA can compute the area of any n-sided polygon, concave or convex, given an ordered list of the (X,Y) coordinates of its vertices. The computation of area takes place in two stages;

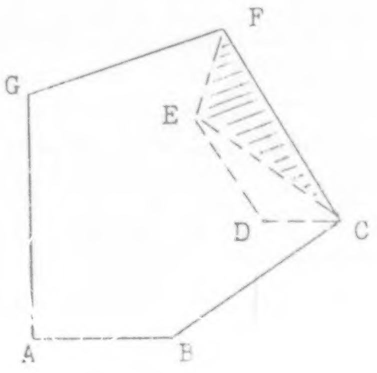
(1) PAREA traverses the polygon eliminating concave points, summing the areas of exterior triangles including these points and creates a convex polygon;

(2) PAREA computes the area of the convex polygon by summing the areas of a set of its interior triangles and subtracts the total area of external triangles to yield the correct area.

An example follows to clarify the above description. The figure below shows a concave polygon ABCDEFG. PAREA examines each point in relation to its preceding and succeeding points to determine whether or not the point represents a concavity of the polygon. PAREA starts with







the points A, B, and C and examines B to determine if it falls to the "left" of the directed line segment AC . This would imply that B is a concave point. As shown, B is a convex point, however, and PAREA continues by looking at B, C, and D . Looking at C, D, and E PAREA encounters a concavity at D . D is eliminated and the area of the external triangle CDE is computed. Since D has been eliminated, PAREA continues traversing the polygon by looking at E, F, and G and on around to F, G, and A. Note that in the case of two or more consecutive concave points they will not all be eliminated in one pass around the polygon. PAREA continues traversing the figure until it makes a pass in which no concavities are eliminated. Thus on the second pass, E is discovered to be a concave point and the area of CEF is computed. At this time PAREA constructs all the interior triangles of the new convex polygon ABCFG containing point A and not both of its adjacent points. Thus triangles ABC, ACF, and AFG are constructed and their areas are computed. The sum of the areas of these three triangles is the area of ABCFG. Subtracting the sum of the areas of triangles CDE and CEF, PAREA thus computes the area of ABCDEFG.

The algorithm PAREA uses to determine if a point falls to the left of a line and thus represents a concavity can be shown in a decision table. Given the coordinates of three points (X_1,Y_1), (X_2,Y_2), and (X_3,Y_3) we wish to determine if (X_2,Y_2) falls to the left of the directed line segment whose end points are (X_1,Y_1) and (X_3,Y_3). The decision table is the completed extension of the following reasoning. The slope M of the line from (X_1,Y_1) to (X_3,Y_3) is $(Y_3-Y_1)/(X_3-X_1)$ and its Y intercept B can be given as $B = Y_1 - MX_1$. If the quantities (Y_3-Y_1) and (X_3-X_1) are both positive and $Y_2 - MX_1 - B$ (substituting (X_2,Y_2) in the equation of the line segment being analyzed) is positive then (X_2,Y_2) can be said to fall to the left of the line and is therefore a concave point in a polygon. If the quantity $Y_2 - MX_2 - B$ is 0 then (X_2,Y_2) is colinear with (X_1,Y_1) and (X_3,Y_3) and if it is negative, (X_2,Y_2) falls to the right of the line segment. Analyzing by cases yields the following decision table:

$Y_3 - Y_1$	$X_3 - X_1$	$Y_2 - MX_2 - B$	(X_2,Y_2)
+	+	+	concave
+	+	-	convex
+	-	+	convex
+	-	-	concave
-	+	+	concave
-	+	-	concave
-	-	+	convex
-	-	-	concave

In case $(X_3 - X_1) = 0$ which would yield an infinite slope (a vertical line) and cause a divide fault in the computer, PAREA examines the direction of the line and the relationship of the X_2 coordinate to either X_3 or X_1 to determine if (X_2, Y_2) is a concave vertex of a polygon.

APPENDIX D

Examples of the Assignment Algorithm

In this Appendix, three examples of the assignment algorithm are shown. All of the examples are taken from simulation runs in the detailed mode so that the scores of spaces which were being considered for assignment would be available. Table D-1 which gives the areas and inventories of spaces in School A is reproduced from Chapter 7 for the reader's convenience.

Example 1

The requirements for the five sections of Science scheduled at 11:30 are shown in Table D-2. Following the requirements for a section is a list of the spaces which were considered for that section and their scores. Section 5, for example, requires 10 tables, 58 chairs, 1 blackboard and 1865 square feet of space. Space C11 has 53 desks, 53 chairs, 2 blackboards and 2 sinks and is given a score of 264.00. The partial scores are .914 for the chairs, .731 for the desks (desks have a default value of 80% of what the score would have been for tables) and .995 for the area of the space--which sum to 2.64. When multiplied by 100, this yields the value of 264.00. C11 is the first ranked space for Section 5, and since there are no conflicts, it is assigned to that section. (Table D-3 shows the complete assignment for the time step.)

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TABLE D-2

POTENTIAL SPACES AND SCORES FOR FIVE SECTIONS OF SCIENCE

```
  ACTIVITY = SCI     SECTION   2  REQUIREMENTS.
 CONF= RAD       DF=3  AREA REQ.=    238
    3 TABLE        17 CHAIR
    1 BB
ACTIVITY  SCI     SECTION    2
SPACE = C30     SCORE =     322.55
SPACE = C41     SCORE =     255.13
SPACE = C64     SCORE =     212.77
SPACE = C23     SCORE =     198.74
SPACE = C47     SCORE =     198.46
SPACE = C20     SCORE =     197.48
SPACE = C25     SCORE =     189.08

  ACTIVITY = SCI     SECTION   5  REQUIREMENTS.
 CONF= CIR       DF=1  AREA REQ.=  1856
   10 TABLE        58 CHAIR
    1 BB
ACTIVITY  SCI     SECTION    5
SPACE = C11     SCORE =     264.00
SPACE = C13     SCORE =     229.20
SPACE = C21     SCORE =     229.03

  ACTIVITY = SCI     SECTION   3  REQUIREMENTS.
 CONF= RAD       DF=2  AREA REQ.=    308
    4 TABLE        22 CHAIR
    1 BB
ACTIVITY  SCI     SECTION    3
SPACE = C42     SCORE =     243.77
SPACE = C28     SCORE =     198.70
SPACE = C40     SCORE =     187.60
SPACE = C25     SCORE =     185.71
SPACE = C47     SCORE =     161.04

  ACTIVITY = SCI     SECTION   4  REQUIREMENTS.
 CONF= CLU       DF=1  AREA REQ.=    696
    5 TABLE        29 CHAIR
    1 BB
ACTIVITY  SCI     SECTION    4
SPACE = C46     SCORE =     255.40
SPACE = C31     SCORE =     113.02
SPACE = C26     SCORE =      54.31
SPACE = C21     SCORE =      48.56

  ACTIVITY = SCI     SECTION   1  REQUIREMENTS.
 CONF= CLU       DF=2  AREA REQ.=    576
    5 TABLE        24 CHAIR
    1 MS
ACTIVITY  SCI     SECTION    1
SPACE = C46     SCORE =     233.61
SPACE = C31     SCORE =      40.73
SPACE = C26     SCORE =     -51.04
```

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TABLE D-3

ASSIGNMENTS OF FIVE SECTIONS OF SCIENCE

```
TIME...11:30

ACTIVITY   SEC.   NO.STUD.   AREA REQ.   SPACE   AREA   REQ:USED
  SCI       5        58        1856       C11    1865     1.00
  SCI       3        22         308       C28     312      .99
  SCI       1        24         576       C46     568     1.01
  SCI       4        29         696       C31    1095      .64
  SCI       2        17         238       C30     203     1.17

AREA REQUIRED     3674 SQ. FT.    AREA   USED      4043 SQ.FT.
```

When Section 5 is assigned space C11, space C42 is eliminated from the potential space list of Section 3. Section 3 is then assigned to space C28, its next choice. Section 2 receives its first choice, space C30.

Sections 1 and 4 both list space C46 as their first choice. Section 1 was given space C46 because a greater difference score (192.88) was computed for it than for Section 4 (142.38).

Example 2

A more complicated assignment is shown in Tables D-4 and D-5. Of eight sections of math, three require space C62 (Sections 26, 22, and 25). The difference score is the greatest for Section 22 so it is assigned to C62. Section 26, which had a higher priority than Section 22 lost its best space, but it is now reconsidered for assignment since it is still the highest priority unassigned activity. It competes with Section 25 which, because C62 was assigned, now has C28 as its top ranked space. The difference score for Section 26 is lower than that of Section 25 and C28 is assigned to Section 25. Finally, Section 26 is assigned to space C25. Since there are no other conflicts, each of the remaining activities gets its top ranked space (after superspaces and subspaces of already assigned spaces are eliminated from their lists).

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TABLE D-4

POTENTIAL SPACES AND SCORES FOR EIGHT SECTIONS OF MATH

```
  ACTIVITY = MATH    SECTION  23  REQUIREMENTS.
 CONF= CLU       DF=1  AREA REQ.=   700
   35 DESK          35 CHAIR
    1 BB
ACTIVITY  MATH    SECTION  23
SPACE = C29     SCORE =    222,29
SPACE = C31     SCORE =    183.57

  ACTIVITY = MATH    SECTION  29  REQUIREMENTS.
 CONF= CIR       DF=1  AREA REQ.=   336
   21 DESK          21 CHAIR
    1 BB
ACTIVITY  MATH    SECTION  29
SPACE = C40     SCORE =    197.92
SPACE = C28     SCORE =    192,36
SPACE = C25     SCORE =    178,57
SPACE = C62     SCORE =    177,38
SPACE = C47     SCORE =    169,94

  ACTIVITY = MATH    SECTION  26  REQUIREMENTS.
 CONF= CLU       DF=3  AREA REQ.=   340
   17 DESK          17 CHAIR
    1 BB
ACTIVITY  MATH    SECTION  26
SPACE = C62     SCORE =    205.88
SPACE = C28     SCORE =    191.76
SPACE = C25     SCORE =    177.65
SPACE = C40     SCORE =    132.06

  ACTIVITY = MATH    SECTION  22  REQUIREMENTS.
 CONF= CLU       DF=2  AREA REQ.=   340
   17 DESK          17 CHAIR

ACTIVITY  MATH    SECTION  22
SPACE = C62     SCORE =    205.88
SPACE = C40     SCORE =    132,06
SPACE = C28     SCORE =     91.76
SPACE = C25     SCORE =     77.65

  ACTIVITY = MATH    SECTION  25  REQUIREMENTS.
 CONF= CLU       DF=4  AREA REQ.=   384
   3 TABLE          16 CHAIR
    1 BB
ACTIVITY  MATH    SECTION  25
SPACE = C62     SCORE =    215.21
SPACE = C23     SCORE =    181.25
SPACE = C40     SCORE =    120.68
SPACE = C46     SCORE =     74.58
```

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```
  ACTIVITY = MATH   SECTION  24  REQUIREMENTS.
 CONF= CLU      DF=4  AREA REQ.=   192
    2 TABLE        8 CHAIR
    1 BP
ACTIVITY  MATH   SECTION  24
SPACE = C30    SCORE =   244.27
SPACE = C32    SCORE =    95.31
SPACE = C48    SCORE =    94.27
SPACE = C27    SCORE =    85.94
SPACE = C68    SCORE =   -80.52

  ACTIVITY = MATH   SECTION  27  REQUIREMENTS.
 CONF= CLU      DF=1  AREA REQ.=   126
    3 NOFURN
    1 TV
ACTIVITY  MATH   SECTION  27
SPACE = C33    SCORE =   200.00
SPACE = C24    SCORE =   196.83
SPACE = C51    SCORE =   194.44
SPACE = C22    SCORE =   185.71
SPACE = C43    SCORE =   -33.49
SPACE = C61    SCORE =  -233.49
SPACE = C50    SCORE =  -270.32

  ACTIVITY = MATH   SECTION  28  REQUIREMENTS.
 CONF= CIR      DF=2  AREA REQ.=    80
    5 DESK   .     5 CHAIR
    1 BB
ACTIVITY  MATH   SECTION  28
SPACE = C45    SCORE =    76.25
SPACE = C51    SCORE =    51.25
SPACE = C33    SCORE =    42.50
SPACE = C24    SCORE =    37.50
SPACE = C43    SCORE =   -16.25
```

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TABLE D-5

ASSIGNMENTS FOR EIGHT SECTIONS OF MATH

```
TIME...10:10

ACTIVITY  SEC.  NO.STUD.  AREA REQ.  SPACE  AREA  REQ:USED
 MATH      23      35        700      C29   1254     .56
 MATH      29      21        336      C40    391     .86
 MATH      22      17        340      C62    460     .74
 MATH      25      16        384      C28    312    1.23
 MATH      26      17        340      C25    264    1.29
 MATH      24       8        192      C30    203     .95
 MATH      27       3        126      C33    126    1.00
 MATH      23       5         80      C45     61    1.31
 MATH      12      25        500      C42    344    1.45
 MATH      17       3         60      C63     52    1.15

AREA REQUIRED     3058 SQ. FT.    AREA  USED      3467 SQ.FT.
```

Example 3

This example is given to show what happens when there are many requirements for similar space. Table D-6 shows the requirements for eleven Language Arts activities. Sections 29, 30, 31, 32, 34, 35, and 36 all have similar requirements in terms of space and equipment. As a result, the potential space lists for these activities contain many of the same spaces. Sections 27, 33, 28, and 26 have higher priorities than those listed above. The spaces which are assigned to the latter set of activities cause deletions from the potential space lists of the lower priority activities. For example, the assignment of space C31 to Section 33 causes space C51 to be deleted from six potential space lists. As the assignments are made in priority order, all of the spaces on the lists for Sections 34, 35, and 36 are eventually deleted, and so no assignment is made.

To reiterate a point, there still exists space into which these activities may be assigned, however, their areas lie outside the range which was defined as acceptable for consideration. Not assigning these spaces warns a designer of a potential problem.

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TABLE D-6

POTENTIAL SPACES AND SCORES FOR ELEVEN SECTIONS OF LANGUAGE ARTS

```
  ACTIVITY = LARTS  SECTION  27  REQUIREMENTS.
 CONF= CLU      DF=1  AREA REQ.=   576
    5 TABLE       24 CHAIR

ACTIVITY  LARTS  SECTION  27
SPACE = C40     SCORE =    202.88
SPACE = C31     SCORE =     40.73

  ACTIVITY = LARTS  SECTION  33  REQUIREMENTS.
 CONF= CLU      DF=1  AREA REQ.=   546
   13 NOFURN
    1 BP
ACTIVITY  LARTS  SECTION  33
SPACE = C40     SCORE =     71.61
SPACE = C31     SCORE =      -.55

  ACTIVITY = LARTS  SECTION  28  REQUIREMENTS.
 CONF= CLU      DF=3  AREA REQ.=   242
   11 CHAIR

ACTIVITY  LARTS  SECTION  28
SPACE = C41     SCORE =    120.66
SPACE = C23     SCORE =     97.11
SPACE = C20     SCORE =     95.87
SPACE = C64     SCORE =     84.30

  ACTIVITY = LARTS  SECTION  26  REQUIREMENTS.
 CONF= CLU      DF=2  AREA REQ.=   140
    7 DESK        7 CHAIR
    1 BB
ACTIVITY  LARTS  SECTION  26
SPACE = C24     SCORE =     92.86
SPACE = C33     SCORE =     90.00
SPACE = C51     SCORE =     85.00
SPACE = C50     SCORE =    -72.14
SPACE = C49     SCORE =    -99.29
SPACE = C61     SCORE =   -130.71
SPACE = C22     SCORE =   -702.86

  ACTIVITY = LARTS  SECTION  29  REQUIREMENTS.
 CONF= CLU      DF=1  AREA REQ.=   120
    6 DESK        6 CHAIR

ACTIVITY  LARTS  SECTION  29
SPACE = C51     SCORE =     99.17
SPACE = C33     SCORE =     95.00
SPACE = C24     SCORE =     91.67
SPACE = C43     SCORE =     90.83
SPACE = C50     SCORE =   -182.50
```

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```
  ACTIVITY = LARTS  SECTION  31  REQUIREMENTS.
 CONF= CLU      DF=1  AREA REQ.=     60
    3 DESK         3 CHAIR
    1 BB
ACTIVITY  LARTS  SECTION  31
SPACE = C63     SCORE =     86.67
SPACE = C51     SCORE =      1.67
SPACE = C33     SCORE =    -10.00
SPACE = C24     SCORE =    -16.67
SPACE = C60     SCORE =    -61.67
SPACE = C45     SCORE =   -168.33
SPACE = C43     SCORE =   -381.67

  ACTIVITY = LARTS  SECTION  35  REQUIREMENTS.
 CONF= CLU      DF=1  AREA REQ.=     60
    3 DESK         3 CHAIR
    1 BP

  ACTIVITY = LARTS  SECTION  34  REQUIREMENTS.
 CONF= CLU      DF=1  AREA REQ.=    120
    6 DESK         6 CHAIR
    1 BB
ACTIVITY  LARTS  SECTION  34
SPACE = C51     SCORE =     99.17
SPACE = C33     SCORE =     95.00
SPACE = C24     SCORE =     91.67
SPACE = C43     SCORE =     90.83
SPACE = C50     SCORE =   -182.50

  ACTIVITY = LARTS  SECTION  32  REQUIREMENTS.
 CONF= RAD      DF=3  AREA REQ.=     18
    3 DESK         3 CHAIR
    1 BB
ACTIVITY  LARTS  SECTION  32
SPACE = C52     SCORE =    -27.78
SPACE = C44     SCORE =    -27.78
SPACE = C63     SCORE =    -88.89
SPACE = C60     SCORE =   -172.22
SPACE = C45     SCORE =   -405.56

  ACTIVITY = LARTS  SECTION  30  REQUIREMENTS.
 CONF= CIR      DF=2  AREA REQ.=     78
    3 CHAIR
    1 BB
ACTIVITY  LARTS  SECTION  30
SPACE = C51     SCORE =     47.44
SPACE = C33     SCORE =     38.46
SPACE = C45     SCORE =    -55.13
SPACE = C43     SCORE =   -139.74
```

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```
ACTIVITY  LARTS  SECTION  35
SPACE = C63     SCORE =      86.67
SPACE = C51     SCORE =       1.67
SPACE = C33     SCORE =     -10.00
SPACE = C24     SCORE =     -16.67
SPACE = C60     SCORE =     -61.67
SPACE = C45     SCORE =    -168.33
SPACE = C43     SCORE =    -381.67

  ACTIVITY = LARTS  SECTION  36  REQUIREMENTS.
 CONF= FMI      DF=1  AREA REQ.=     60
    1 TABLE        3 CHAIR
    1 BP
ACTIVITY  LARTS  SECTION  36
SPACE = C63     SCORE =      86.67
SPACE = C51     SCORE =       1.67
SPACE = C33     SCORE =     -10.00
SPACE = C24     SCORE =     -16.67
SPACE = C60     SCORE =     -48.33
SPACE = C45     SCORE =    -141.67
SPACE = C43     SCORE =    -341.67
```

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TABLE D-7

ASSIGNMENTS OF ELEVEN SECTIONS OF LANGUAGE ARTS

TIME...11:20

ACTIVITY	SEC.	NO.STUD.	AREA REQ.	SPACE	AREA	REQ:USED
LARTS	27	24	576	C40	391	1.47
LARTS	33	13	546	C31	1095	.50
LARTS	28	11	242	C41	204	1.19
LARTS	26	7	140	C24	130	1.08
LARTS	29	6	120	C33	126	.95
LARTS	34	6	120	@@@@	0	.00
LARTS	32	3	18	C44	41	.44
LARTS	31	3	60	C45	61	.98
LARTS	30	3	78	C43	109	.72
LARTS	36	3	60	@@@@	0	.00
LARTS	35	3	60	@@@@	0	.00
LARTS	15	7	294	C25	264	1.11
LARTS	20	7	168	C30	203	.83
LARTS	23	7	140	C65	142	.99
LARTS	25	47	1034	C29	1254	.82

AREA REQUIRED 3656 SQ. FT. AREA USED 4020 SQ.FT.

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